CASSELL'S TECHNICAL MANUALS

DRAWING

FOR

CARPENTERS

AND

JOINERS

Containing a Description of the Construction of the Subject of each Study and the Method of Drawing it; with Elementary Lessons in Freehand and Object Drawing

WITH

TWO HUNDRED AND FIFTY ILLUSTRATIONS AND DRAWING COPIES

BY

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CASSELL AND COMPANY, LIMITED

LONDON, PARIS, NEW YORK & MELBOURNE. MCMIV

First Edition *May* 1870.
Reprinted August 1870, 1871, 1873,
1875, 1878, 1881, 1882, 1883, 1884,
1885, 1887, 1888, 1889, 1890, 1892, 1894,
1897, 1899, 1902, 1904.

PREFACE.

THIS manual is intended as a sequel to "Building Construction," and requires therefore but few words by way of preface.

Although each of the manuals is, as far as possible, complete in itself, some of them necessarily bear upon others; the student will therefore do well to consult such of the volumes as treat of the general subject, before taking up those which are intended to work out special sections.

The purpose of the present volume is distinctly to teach the styles of *drawing* required by the carpenter and joiner; but in order that the hand may work under the guidance of the mind, as much of the construction of each subject is given as is compatible with the plan of the book.

The course of lessons is so arranged as to combine linear, freehand, and object drawing; each of these branches being again divided and subdivided; and thus, in linear drawing, foundations, piles, coffer-dams, wooden bridges, roofs, staircases, doors, gates, &c., are made subjects of study. Mouldings, borders, scrolls, &c., are included in the Freehand section; whilst, under the head of Object Drawing, a few simple rules of Perspective and shading are given, in order to enable the student to draw with some degree of correctness from the subject

before him: these form an introduction to Practical Perspective, which is treated of in another volume of this series.

With these few words the manual is presented to the public, in the earnest hope that it may prove of service, and remove some of the difficulties which have hitherto obstructed the path of the British workman

ELLIS A. DAVIDSON.

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DRAWING FOR CARPENTERS AND JOINERS.

IN the first volume of this Series, the Elementary principles of Practical Geometry were taught, in order to show the student the relation of lines to each other, and the most scientific (and hence the most accurate) methods of constructing the various forms required in Practical Art.

The second volume embodies the systems of "Orthographic and Isometrical Projection," teaching the methods of constructing drawings of solid forms, of obtaining elevations from plans, and *vice versâ*, of projecting sections from given data, and for developing the surfaces of the various solids.

"Building Construction" forms the subject of the third volume, each branch of that study being treated of in as extended a manner as the limits of a general treatise would permit.

The object of the present volume is a thoroughly practical one—namely, to teach the *drawing* required by Carpenters and Joiners, whose work enters so largely into all building operations. But although the general intention is that the student should learn principles from the former volumes, and gain absolute practice from this, still it is not intended that the end and aim of the examples should be simply to teach artisans to measure the distance from point to point, and rule the lines, under the impression that instinctive *copying* is drawing; there can be no greater mistake than to think of drawing as a manual exercise only. It constitutes the language of

the workshop, more eloquent than words, more rapidly understood, and less liable to be misapprehended.

But these advantages are only the result of intelligent rendering, of a thorough knowledge of the construction, and of absolute correctness in delineation.

The objects of the preceding volumes have been recapitulated, so that the student may clearly understand that a definite plan is being worked out, and that the lessons have been so arranged that those which are absolutely fundamental and necessary alike to the artisans in every branch of industry, should at given points diverge into the special course of studies immediately serviceable to each.

In keeping, however, the object of the book the study of practical drawing—in view, no opportunity has been lost to explain the principles of construction of the subject of each lesson, whilst at the same time the best mode of drawing it has been carefully explained.

The principles of Foundations having been elucidated in the previous volume, it is here proposed to give some studies of the various assemblages of timber employed in such works, in order to afford some useful practice in drawing parallel lines at right angles to each other.

LINEAR DRAWING BY MEANS OF INSTRUMENTS.

Fig. 1 is the plan of a network of timber supporting a platform on which a foundation is to be erected.

Here the transverse sleepers, *a a a a*, rest directly on a site which, although not soft enough to render piling necessary, is still not sufficiently firm to allow the walls of the structure to be raised without the foundation being extended and equalised.

Fig. 2 is the sectional elevation of the sleepers and wall, *a* being the elevation of the cross-sleepers, which are shaded in the plan.

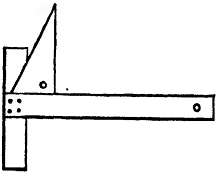
With thus much information as to the meaning of the subjects before him, the student can now commence work; and as I have often known learners waste half of their evening, and when reproached with idleness, say, "I don't know where to begin," it may be well to lay down as

a general principle, that when the position of the whole subject on the paper has been decided upon, the sure plan is to *draw first* that which would be *laid down, or built first.* It is also necessary to say that all the drawings in this book are to be worked to at least twice the size of the examples.

Well then, the sleepers, *a a a a a*, would, of course, be laid down first; and, therefore, these must be drawn first.

Draw the line A B, the front edge of the first cross-sleeper. (Fig. 1.)

This line is to be drawn with the T-square, holding the butt-end tightly against the left-hand edge of the drawing-board. Do not draw it exactly the length of A B, but longer, and set off the length A B upon it, leaving a little of the indefinite line on each side of A B. The purpose of this will be pointed out to you presently.



Next, keeping your T-square in its place against the edge of your board, move it by its butt-end a trifle lower down, place your set-square against it as shown in the cut, and draw perpendiculars from A and B. The immediate purpose of these is to give the ends of all the cross-sleepers; but as they will be wanted for another purpose by-and-by, draw them much higher than they are for the present required: in fact, in all architectural drawing, it is very useful to draw your *pencil* lines *past* their absolute extremities, for reasons which I will explain to you when speaking of inking the drawings.

You will now find it useful to employ two pairs of compasses or dividers. In the one, take the thickness of the sleepers; and in the other, the width of the space between them. From A B set off on the perpendicular A C the width of the first one, then a space, then another sleeper, and so on; and draw the lines which give the edges of the sleepers.

It will, of course, be remembered, that too hard a pencil should not be used, so that the superfluous lines may be easily rubbed out after inking, and that the pencilling must be done as lightly as possible, so that no more of

the grit of the lead than is absolutely necessary may be left on the paper, for this will work up between the nibs of your draw-pen, and cause endless annoyance and difficulty.

With the same widths in your compasses, mark off the sizes of the longitudinal sleepers, *b b b b*, which rest on *a a a a a*; and across these again draw the planking, *c c c c c*, the lines forming the ends of these planks to be drawn within the lines A C and B D.

To draw the sectional elevation (Fig. 2), draw the ground-line, E F, and the line above it, *d e*, representing the height of the cross-sleepers, of which *a* is the elevation.

Produce the lines of the longitudinal sleepers in the plan ; these will give the sides of their sections in Fig. 2, and across these draw the edges of the planking, *c*, parallel to the lower sleeper. It will be seen that the under sides of these sections are lower than the upper edge of the lower sleeper ; this is because they are notched on to it in the manner shown in "Building Construction," page 100, Fig. 107.

On the platform thus constructed draw the section of the pier or wall.

It may be mentioned that the spaces between the sleepers should be well rammed or flushed up to the top of the sleepers– the planking may then be said to rest on a solid basis—and planks should be spiked to the sleepers with wooden pins.

Fig. 3 is the plan and Fig. 4 is the sectional elevation of a platform in which the longitudinal sleepers, *b b b*, rest directly on the ground, and are kept in their places by the cross-sleepers, *a a a a a a a*, which rest upon them. These are notched down, so that only half their thickness stands above the longitudinal sleepers. The spaces between these having been duly flushed up as in the previous example, the planking, *c c c*, is placed *between* the cross-sleepers, of a thickness equal to the portion of their thickness which stands above the longitudinal timbers, the upper faces of the cross-sleepers themselves thus covering a portion of the surface of the platform.

To draw these figures, draw a line at A B, for the ends of the longitudinal sleepers ; mark off the widths of these and of the spaces between them.

Now, knowing that the elevation is to be projected

from the plan, you may as well carry on the process at the same time that you are drawing the first figure; therefore, at the proper distance, draw the ground-line of the elevation, C D, Fig. 4, and as you draw the longitudinal sleepers, carry down the lines which will give you the ends or sections of the timbers lettered *b b* in the elevation.

Returning to the plan, draw the cross-sleepers, *a a a a a a a*; and the lines parallel to the longitudinal sleepers (not shown in the example) which bound the ends of the cross-sleepers, carried up, will give also the ends of the same timbers, and of the planking in both plan and elevation. It will be seen that the portion of the cross-sleeper which is notched down on to the longitudinal timbers is represented by the width at *a* in the sectional elevation.

The section of the wall may, of course, now be drawn either to pattern, or may be worked to represent brickwork from either of the footings of walls given in "Building Construction."

These drawings may now be coloured to represent fir, the colour usually employed for this purpose being raw sienna. This should be washed thinly over *all* the wood-work, and when dry the lower sleepers should be covered with sepia, the shadows cast by the upper on the lower timbers to be subsequently added with colour rather darker. When all the colouring is dry, the lines representing the graining are to be freely, but not too heavily, executed with this last darker shade of sepia; and it must be borne in mind that the graining is but secondary, and must not be over-done, and that in the example the lines are engraved closely in order to darken the lower timbers, so that the cross-sleepers may be more plainly visible; but in your drawing you attain this end by the wash of sepia, and therefore you are not required to shade your work in lines. In the ends of the sleepers shown in Fig. 4 it is, however, necessary to draw lines at 45° in order to show that they are meant to represent sections.

Fig. 5 is the plan and Fig. 6 is the sectional elevation of the planking for the foundations of walls meeting at right angles. This plan, taken from an excellent German example, is such as might be applied in a case where it

might not be necessary that the whole of the area should be planked.

To draw this example, draw the line A B, Fig. 5, and B C at right angles to it.

On B C mark off the widths of the lower sleepers and the spaces between them, and from these points draw the lines required for the timbers.

On A B mark off the widths of the upper sleepers and the spaces between them.

Although only three of these are continuous, it is advisable to draw all in pencil as if they were so, which ensures the distant set being immediately opposite to those in the front; and this mode of working is decidedly the more rapid.

It has been mentioned that it is desirable to draw all pencil lines longer than they will be required. We will now inquire why it is so.

Let us suppose the whole plan finished, as far as the pencilling is concerned, and that the next process is to be that of inking.

Now, of course, you know that the beveled edge of your rule must be turned *downward*, in order to raise the edge so that the ink from the draw-pen may not drag against it. This edge, however, obstructs, in a degree, your view of the lines you are to ink, and you either draw your pen past the angles of them, or do not rule quite up to them. In either case the result is disagreeable, for you have either to scratch out the superfluous ends, or to patch the line, which is exceedingly difficult to do neatly. But if you have drawn out the pencil-lines forming the edges of the sleepers, you at once see the exact length you are to ink; and this same result in inking the long lines will be attained by the pencil-line previously drawn at D E.

You are further advised never to scratch out any extraneous line until *after* you have coloured, and the drawing has thoroughly dried, as otherwise the colour will run into the roughened paper and cause a blotched appearance.

The sectional elevation can now be projected from the plan in the manner already explained. The shadow cast by the wall (which is a section on the line *y x*) is to be washed in with sepia. Be careful not to mix your

colour too thick. Rather repeat the wash in order to darken it.

The lines for the courses of stones should be drawn after the colouring and shadowing, so that they may not be washed away.

OF FREEHAND DRAWING.

At this stage it is advisable that the student should be informed that *all* the drawing which is necessary for the artisan cannot be done with *rules and compasses*, but that some portion of the work must be drawn by "freehand."

It is important that a workman should be able, with his piece of chalk or pencil, to sketch roughly, by hand, the form of any object he is required to make, or that, visiting any exhibition or foreign country, he should be able to bring away with him drawings, however roughly done, of any tool, appliance, useful or ornamental article which may have attracted his attention.

Again, as the examples contained in this or any other work of a similar character advance, it will be seen that curved lines are of constant occurrence; and although some of them, which may be composed of arcs of circles, may be done with compasses, and others may be inked by means of the French curve, there will still be found many which cannot be executed by any other means than by freehand, and there will occur little pieces of curved lines continuous with straight ones, which can always be more neatly joined by hand than by instruments, or which a certain amount of practice will enable the draughtsman to execute, with his pen or pencil, in less time than it would take him to find the centres. But this is not all. The study and practice of freehand drawing gives accuracy to the eye and refines the perceptive faculties; it enables a man to raise his ideas beyond mere straight lines, to cultivate his taste, and in many ways to add beauty to utility.

To the joiner these remarks apply with even greater force than to the carpenter, for there is so much in his work that requires taste and refinement, that to him hand-drawing and a proper cultivation of taste are absolutely indispensable. The Germans (amongst whom technical

education has from early times been well attended to) imply this in the very names they give to the different departments of the workers in wood. They do not seem to consider the work of the house-carpenter to be merely making a good joint or planing wood very skilfully, and, therefore, do not use the term "joiner." They call the workman "Bau-tischler" (the building, cabinet, or table maker), and the "Fein-zimmermann" (the *fine room-man*); and these terms will at once be understood as conveying the meaning that from the joiner, not only neatness but taste is required; and he cannot acquire this, or even cultivate that which may be (and in many cases *is*) natural to him, without patiently studying and practising the delineation of beautiful forms which Nature spreads so bountifully around, and which men of former periods have produced. The South Kensington Museum, a perfect art-world, contains innumerable specimens of the application of art to trade purposes, and the student is strongly urged to avail himself of the advantages of such an exhibition, and of the excellent tuition given in the numerous schools of science and art, spread not only over London, but throughout the provinces.

The object of introducing freehand drawing at this stage is that the student may practise it, little by little, as he progresses with his linear drawing, and so cultivate both branches equally. This will be found more satisfactory than allowing the study of ruling-work to outstrip hand-work; for, where this is the case, whilst the ruled lines may be exceedingly well done, the curved parts will be so clumsily added that the appearance of the drawing will be quite spoilt.

It is intended to introduce at a further stage the elements of ornamental forms, but in commencing, it is deemed best that the subjects should be such as are well known to the student; he will then be able to check his own work, for he will at once see whether his drawing is really like the tool he has in his basket; and I would hope that it may lead him to try to make drawings of others direct from the objects and unaided by copies.

We commence, then, with Fig. 7, which, it is hoped, is sufficiently clear to be identified as a screwdriver, and this example, simple as it is, will afford excellent practice in a most important branch of the study—the balancing of parts,

Here the perpendicular A B is to be drawn first, and, when this is accomplished (by *hand*, not by means of the rule), proceed in the following manner:—

Draw the lines *c d* and *e f*, crossing A B at right angles; observing, but *not* measuring, the distance between them. Next draw the line *g h*, which is to form the edge of the blade; and also dot fine lines across at *i j* and *k l*.

All these lines are, in the first instance, to be drawn of indefinite length.

The two points to be observed are—

1. That they are at the proper distances apart.
2. That they are all really at right angles to A B.

Now mark off on each side of the central perpendicular the length of half the diameter of the brass ring, and draw the lines *c e* and *d f*.

The handle is to be drawn next, and this is formed of a continuous curve. Begin at A, and in the lightest manner possible sketch the curve extending to *c*. Adopt as a constant rule, that when two curves are to be balanced, it is advisable to draw the *left* side first, for if the right side were drawn before the other, you would most likely cover it with your hand whilst sketching the left; this would, of course, render your getting your two sides alike very difficult.

When, then, you feel in some degree satisfied that the left side of the handle is nearly correct, add the curve from A to *d*.

Observe.—*There must not be a sharp point at* A. The two sides must merge smoothly into each other at the top, so as to form one complete curve.

You can well imagine how very absurd a screwdriver would appear, and how very unfit it would be for work, if it had a sharp point at the top of the handle.

Now commence the blade, by drawing the perpendiculars *e i* and *f j*; then the curve *i k*, on the left side, and *j l* on the right.

Mark off on *g h*, on each side of the perpendicular, half the width of the edge of the blade, and then draw the lines *k g* and *l h*, which will complete the form.

Now this will constitute the rough sketch. The next step is to convert it into a *drawing*. Pass your india-rubber lightly over the pencil-lines, so as to remove as much lead as possible, without entirely erasing the form.

Observe.—In using india-rubber, it is better to rub in the *direction of the lines* rather than *across* them; and when there is much lead upon the paper, it is better that the friction should be rapid and light than slow and hard; the rubbing should not be backward and forward, by which the lead rubbed off by one stroke is rubbed on again by the next; but the action should be like planing or filing--namely, in one direction, the rubber being raised in the backward motion.

The paper should at this stage present a perfectly clean appearance, with a very clear but slight trace of the form.

Now, with a fine, cleanly-cut point to your pencil, trace over the outline, avoiding all raggedness, and endeavouring to get each line of the same thickness throughout; those on the right side are to be rendered a little darker than the others. This process is called "lining in."

Fig. 8 represents a pair of compasses, such as are commonly used by joiners. In beginning this simple subject, draw a horizontal line, and on it erect the perpendicular A B.

From A set off A C and A D, and joining B C and B D, complete the triangle C B D.

The apex of this triangle will be the centre of the rivet. Draw the small circle around this point, and the larger circle for the head of the compass.

Next draw the lines E C and F D, which form the outer sides of the instrument, and which are slightly curved. The inner sides to G and H are straight, and are portions of the triangle previously drawn. The lines I and J correspond with the outer edges, of which, indeed, they form portions when the compass is closed.

Fig. 9 is an outline of a shaping-knife, and you will require but very few instructions for copying it. Draw a horizontal line for the back of the tool, and two lines at right angles to it, which are to form the centre lines of the handles. The instructions given in relation to the handle of the screwdriver will serve for these as well; but you must be careful to get the two handles *precisely* alike. When this is accomplished, draw the edge of the blade parallel to the back, and then complete the curved portions by which the blade is united to the handle.

Fig. 10 is a sketch of a chisel, and with the hints already given, I do not think you can require any special instructions in regard to it.

LINEAR DRAWING BY MEANS OF INSTRUMENTS (*continued*).

Returning now to the practice of drawing by means of instruments, a useful series of examples is given in the annexed sheet.

The subject of which Fig. 11 is the plan and Fig. 12 the section, is a network platform for a foundation where the soil is of a soft character, and liable to be pressed outward by the weight resting upon it, but still not sufficiently so to render absolute sheet-piling necessary. Strong piles (*c c c c*) are driven down to the firm soil, and these are connected by horizontal planks (*e e*), placed on each side and bolted through the piles.

Now, in the space left between these planks a wall is formed of timbers, *d d d d*, which are driven down by hand-ramming, not extending downward further than the circumstances may render necessary.

These planks are jointed in various ways, with some of which you have already become acquainted in the study of "Building Construction," viz., Fig. 13, rebated; Fig. 14, splayed at one edge and recessed at the other; Fig. 15, ploughed and tongued. In the example, the tongue is shown square and tapered, and in Fig. 16 it is worked in the dovetail form, whilst Fig. 17 shows the planks joined by an inserted tongue.

Now, to draw this Series of Examples—

First draw the piles, *c c c c*, and continue the lines forming the edges of them, so that these may give you the sides of the piles shown in the section, Fig. 12.

Next draw the top of the wall of planks between the piles, and in the example it will be seen these are one-third the thickness of the piles; therefore, divide the edge of one of the piles on each side into three equal parts, and use the middle division for the thickness of the wall. This thickness, again, projected upwards, will give the elevation of the edge of the planks (*d d*). Now, outside and inside of the piles draw the tying-planks, *e e e e*, and project them on to Fig. 12, *e*, where it will be evident they will appear as sections.

Next draw the lower course of sleepers, *a a a a a*, and the elevation of them shown at *a*, in Fig. 12; then follow

in their order the upper course of sleepers, *b b b b*, their projection in section, *b b b b*, and in these last the flooring of the platform which has not been shown in the plan.

The difference in the form of the piles when used separately, or at angles of foundations, and those called sheet-piles, has been mentioned when treating of the principles of foundation in "Building Construction." The cuts are here repeated, Figs. 18 and 19, in order that they may be used as studies for drawing and shading. To save reference, it may be well to remind you that the points of the single or corner piles are four-square, whilst those of sheet-piles are only beveled from *two* sides, and the edge is cut so as to slant downwards.

Piles are generally worked of square timber, and if the trees admit of it, those which are to be rammed entirely into the ground are mostly slightly tapered downwards throughout their whole length, and are shod with iron at their points (unless the piles be small and the ground not very hard); and an iron ring is placed around the upper end, to prevent the piles from splitting by the violence of the blows necessary to force them down.

Sometimes, however, the piles which are to be driven quite below ground, may be used without squaring; two illustrations of such (Figs. 20 and 21) are here given, to afford practice in shading cylindrical bodies.

Having pencilled and inked the outlines of the four piles shown in the example, wash over the part representing wood with a pale tint of raw sienna. In the two square piles this wash may be perfectly flat, but in the round piles the tinting must be in accordance with the form.

It will be evident that when a cylindrical body is placed upright, the light will fall in a stream straight down the part which projects the most, and this part must therefore, be preserved as bright as possible; in fact, there must be a perfectly white streak extending all the way down.

To effect this, you must use two brushes, the one rather larger than the other. Take some colour in the smaller one, and dip the other in water; touch the points of both on another piece of paper, so that they may not be overcharged, and by gently turning each round as you draw it along the waste paper you will bring the hairs to a point.

Now commence by drawing the brush containing the colour down the left side of the round pile, carefully avoiding passing over the line by which it is bounded. In this way colour a strip about one-eighth of an inch wide; do not leave a *pool* of colour, but merely tint the paper. Now, before this has time to become dry, take your water-brush, and passing the point down the *inner* side of the part you have coloured, soften the edge away so that the colour may merge gradually into the bright white. Leave about the eighth of an inch quite dry, then pass your water-brush down, and next to this the colour, so as to produce the effect as on the other side; the colour becoming gradually fuller as it becomes further removed from the light.

The shading is to be done in sepia; in the square piles this will simply consist in tinting the shaded sides with a flat tint. In the round piles, however, the shading must be managed in a similar manner to the colouring; dipping your middle-sized brush into the sepia, colour a strip the whole length of the pile. This darkest part, however, you will observe, is near, but *not* really on the outer edge of the cylindrical body. Further to the right side, you will notice the shade becomes lighter, and this is called the *reflected light.*

Whilst the dark strip is still moist, wash off its edges, and merge it off into the local colour of the pile, and this should be done so gradually that as you ought not to be able to discover where the white light merges into the raw sienna, so you should not be able to discern the meeting of that colour with the sepia; but do not work your brushes up and down so as to produce a sleek or woolly effect. The shading and tinting should be bold and clear: a little practice will enable you to accomplish this. I therefore advise you to repeat such studies until you succeed. The iron shoe of the pile will, of course, be coloured with pale indigo.*

Fig. 22*a* will afford another example for colouring and shading. The drawing represents the side elevation of the monkey (or rammer), and guide-posts of a simple pile-driving machine, with head of a round pile.

The rammer, which would be made of beech or other

* See technical colouring, "Building Construction," page 16.

hard wood, should be tinted of a lighter colour than the guide-posts.

The pile is to be coloured and shaded as in the previous examples, but you will observe that there is on it the shadow cast by the rammer above; this is called the "cast-shadow," and must not have its lower edge smoothened off, as the sharp edge of the bottom of the rammer will cause the shadow cast on the cylindrical pile to be very well defined.

Fig. 22*b* is the front elevation of the same object, and will give further practice. The student is urged to observe the forms and tones of shadows cast by different objects; this he can easily manage—a cubical piece of wood or two, and a cylindrical piece, may be disposed in hundreds of ways, each affording a new study. This is the only way to gain real practice, for so long as the pupil only copies, he is merely repeating other men's works, and will only gain manual practice; *whilst by studying and making his own observations he will be laying up a store of information of which he will hourly find the value.*

The scientific projection of shadows will be fully entered upon in another volume of this series, as will also perspective and object drawing; but in order that you may be able to carry out the suggestion just made, it is necessary that you should have a few hints as to the mode of proceeding. I therefore intend giving you an occasional chapter on

SKETCHING FROM SOLID OBJECTS.

I will, in the first case, suppose you sitting at a table, the edge of which is parallel to your chest. Let the rectangle here drawn, Fig. 23, represent the top of the table, and let your position be at A. Now on the opposite side of the table are placed three equal blocks of wood, which are square at their ends, and are doubly as long as they are thick.

Carpenters and joiners, to whom this book is principally addressed, will have no difficulty in providing themselves with three such blocks; a very convenient size is four inches square by eight inches long; but, of course, the principles about to be explained would apply to solids of any size or of any proportion.

Place a model (1) on one of its long faces, with its square end parallel to the edge of the table, B C. All its long edges, as *b c* and *a d*, will then recede at right angles to the square end.

Place another block (2) so that whilst resting upon one of its long sides another is immediately in front of you, its long edges being parallel to B C; and, finally, place the third block (3) on its end, so that one of the long faces in the front, and the other at the back, may be upright, and parallel to B C, the object standing thus on your right hand. Of course you will remember that the rectangles 1, 2, and 3 are called the "plans" of the objects.

Now attempt, guided by the following figures, to draw these models as they appear to you from the position in which you are placed.

First draw the square *a b e f*, Fig. 24, which will represent the end of the object, which you will remember is vertical and parallel to the edge of the table (and you must bear in mind also that you are to sit so that your chest is parallel with the table as well).

Now it will be clear to you, that if an object were placed lower down than your eye, you would see the top of it, as you see the top of a box when standing on the floor; and that if another object were placed above your eye, you would see the bottom of it, as you see the underneath surface of the floor of a birdcage hung up against the wall.

This, then, is the first point to be settled by asking yourself, "Is my eye higher or lower than the object?" You will, of course, be able instantly to decide this. Next, think, "As my eye *is* higher than the block, about *how much* higher is it?" This, too, you will soon be able to decide by trying how many times its own height you could raise the block before you lose sight of the top.

When you have decided on the height of your eye in relation to the model, draw a horizontal line across your paper, which shall have the same height in proportion to the square you have drawn as the real height of your eye has to the model. That is, supposing you see that your eye is three times the height of the model above its surface, then draw a line at three times *a f* above *e f*. In the illustration a different height is taken, the object being to cause the student to *use his own judgment* instead of merely

copying the diagram. This line (H L) is called the horizontal line, and so we come to the definition –

The Horizontal Line represents the height of the eye of the spectator.

Now if a sheet of glass were placed upright between your eye and the object, and this line were drawn upon it, then, when you looked straight forward, the point on the horizontal line immediately opposite your eye would be called the point of sight, so that we have here a second definition : -

The Point of Sight, or Centre of Vision, is the point in the picture which is immediately opposite to the eye of the spectator.

Looking straight forward, then, is your eye on the left or right of the object? Well, in this case it is obviously on the *right*, and how much it is so, you must judge in the same way as you did in the matter of the height, viz., by comparing your distance with the length of object, and then marking the point of sight (P S) on the horizontal line. I must here tell you a short rule .—

All lines which in the object are at right angles to the plane of the picture must be drawn to the Point of Sight.

On referring to Fig. 23, you will see that, supposing the sheet of glass (the picture-plane) to stand on D E, then the line *b c* of the model would be at right angles to it, and therefore from *b*, Fig. 24, draw a line to the point of sight. But *all* the long edges are parallel, and thus the same rule will affect them equally ; therefore draw lines from *e* and *f* to the point of sight.

Portions of these convergent lines will, as you can easily understand, form the edges of the solid, and you must terminate them by the perpendicular *g h* and the horizontal *h i*. It is not at present my intention to give you any rule for obtaining the distance of *g h* from *b e*. This must be deferred until you study perspective by means of instruments.* At this stage you must use your judgment, and you will find that you will, with but very little practice, be able to form a very just idea of the distance, for you will see

* See "Practical Perspective," Cassell's Technical Manuals.

that if the lines had been drawn at either of the places indicated by dots, the object would, in the one case, appear as a mere flat piece of wood, whilst in the other it would represent a long balk of timber.

The plan of block No. 2 will show you that in this figure the *length* of the block is parallel to the picture-plane, the narrow edges receding. To begin this representation, draw the rectangle, *b e h g* : *b g* being double *b e*.

Now you will at once perceive that, as the block is immediately in front of you, you do not see either its left or right side, but only the top. On referring to the last view you will be reminded that the ends *a b*, which in that case were parallel to the picture, are now at right angles to it. Therefore from *e* and *h* draw lines to the point of sight. Then the line *i f*, parallel to *e h*, will complete the top, and the figure will thus show the front and top only.

Now proceed to sketch Fig. 26, which is the view of the block when standing on its end on your right side. Here, again, as the face is parallel to the picture, the front consists of the rectangle, *e b h g*. Having completed this, draw lines from *e* and *h* to the point of sight. Then the line *i f* will give the distant perpendicular, and thus the view will consist of front and side only, for, as its end, *h g*, is higher than the horizontal line, you cannot see the top. Of course, you will understand that all the blocks need not necessarily be the same size; in fact, as you are placing your height at three times that of the square end, it will be necessary that this last one should be longer than the others, for, as the length of the others is only twice their width, the end will still be under the horizontal line; but whatever be the proportions of the objects to be drawn, and whatever be the height of the spectator, the principles here laid down will apply, and a very small amount of practice, guided by patient and intelligent observation, and urged on by the desire to learn, will soon enable you to judge whether your drawing truly represents the object as you see it.

Fig. 27 shows the mode of rendering a cube or other rectangular object when it is absolutely on a level with your eye, so that you do not see either the top or bottom of it, but, as it is on your left hand, you can see its right side. Of course, if it were placed immediately opposite to

your eye, viz., at the point of sight, you would only see the front, but neither top, bottom, nor sides.

Fig. 28.—The object here represented is a plank, the *end* of which is parallel to the picture, and the length at right angles to it, the whole object being placed *above* the level of the eye of the spectator (supported or suspended by means not shown in the drawing).

It will be evident that, as the long edges of the plank are at right angles to the end, they will run directly from it into the distance, and will thus be drawn to the point of sight, the lines forming the distant end being parallel to those seen in the front.

Fig. 29.—This object consists of four pieces of wood mitred together so as to form a piece of framing, or the sides of a shallow box.

Here, again, the side, *a b c d*, which is parallel to the front, is to be drawn of its proper dimensions, and this being done, lines are to be drawn from each of the angles to the point of sight. The lines *e f* and *f g* will then complete the general view of the object as it would appear if it were a solid block.

I must call your attention to this plan of drawing the *general outline* of the whole object before attempting the detail. It must be evident that the whole of the interior lines, and all the detail, must depend entirely upon the outline of the object as a whole, and, therefore, I impress this system upon you.

The under surface of this slab, then, although in reality *square*, will in your drawing be represented by the irregular four-sided figure, *c d f g*.

Draw the diagonals *c f* and *d g*.

Now from *c* and *d* mark off on the line *c d* the distances *c h* and *d i*, equal to the thickness of the pieces of wood of which the object is made, and from these points, *h* and *i*, draw lines to the point of sight.

The line drawn from *h* will cut the diagonals in *j* and *m*, and the line drawn from *i* will cut the diagonals in *k* and *l*.

Draw a line from *j* to *k*, and another from *m* to *l*; strengthen the lines *j m* and *k l*, then the figure *j k l m* will represent the inner square, or inner edge of the wood of which the framing is formed.

The perpendicular at *m* represents the vertical junction of the inner sides of the framing. This completes the

sketch, which may now be "lined in" — that is, put in clean lines, in the manner already shown.

Fig. 30 is a view of the same object, when placed vertically and on your right side. The same lettering has been retained, and this will guide you in sketching the frame up to the stage shown in the last figure; but the present study is an advance upon the previous one, for you can *see through* this, and it is, therefore, necessary to find the width of the distant side, which will, of course, be diminished by its being removed from the front of the picture.

From *h* draw *h n*, which is of course the real width of the side, and from *n* draw a line to the point of sight.

Now from *m* draw a horizontal line, which will cut this last line in *o;* then *m o* represents the length of *h n*, when thus far removed from the plane of the picture.

Draw the perpendicular *o p*, strengthen as much of *n o* as is visible, and the sketch of the object will then be completed.

This section of our subject will be reverted to in a future chapter; meanwhile, I earnestly advise you to make constant attempts at sketching from the simple objects around you. Do not say, "Where is the use of drawing common blocks of wood?" A great sculptor of old said, "Every block of stone contains a statue—if we only knew how to remove the superfluous matter;" and depend upon it, the knowledge, and consequently the power, you will obtain by drawing these solid forms, will enable you to delineate those of a far higher and more complicated character; for, however gracefully you may decorate your work, unless the object be correctly represented, the ornamentation will be only misplaced.

LINEAR DRAWING BY MEANS OF INSTRUMENTS (*continued*).

Fig. 31 is the section of a dam, or wall of planks, which confines the soil subject to the action of water. Of course, the strength required for such a dam must depend on the height of the water-level—that is, the wall must be strong in proportion to its height. The following figure is one of the simplest of these constructions, and consists of piles, placed at a distance from each other, which must be

regulated, first, by the nature of the soil at the back of the dam, and its tendency to press forward; and secondly, by the thickness of the planks employed for the wall, which must be such as to resist their being bent by the force of the soil they confine. Of course, the more such

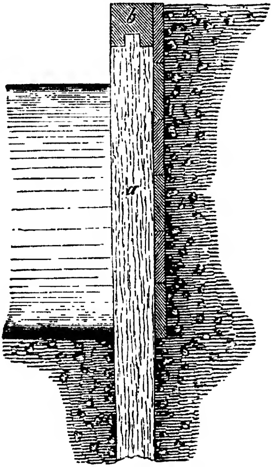


Fig 31.

pressure is to be expected, the closer must the piles be placed.

The piles are in the above example connected at the top by a cross-timber, into which they are mortised. The planks are then placed horizontally at the back of the piles; and may be united by the methods shown in Figs. 13 to 17.

The drawing in this subject is very simple. First, the pile *a*, with section of the cross-beam *b*; next, a line parallel to the inner side of the pile, and at a distance

from it equal to the thickness of the planks of which the wall is to be constructed; between these two lines short horizontals are to be drawn, or the joints of the edges shown, according to the method adopted.

Fig. 32 is the section of a dam used in cases where the

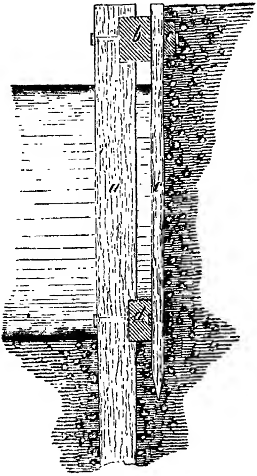


Fig 32.

soil is very swampy in character, or where the external water might pass through fissures in the bed of the stream, and so enter the foundation at a lower level than the bottom of the wall adopted in the previous case. The plan here adopted is to drive in the strong piles *a*, and to connect these by the cross-timber *b*, partially sunk and temporarily fastened on to them. Another timber, *d*, is then to be laid on the bed of the water, parallel to *b*, and this is also to be bolted on to the piles, and at the back of these the wall of perpendicular planks, united at their

edge by one of the methods already shown; or, sheet-piles, *c*, may be used—these are driven down far below the bed of the water, as the circumstances may require.

Each of these planks having been driven until it reaches more solid soil, the strong rail, *e*, is placed at the back of them, and a bolt passing through *e*, *b*, and *a* binds them all firmly together; the heads of the planks are then sawn off to one level.

Fig. 33 is a section of one of the walls of a coffer-dam. A coffer-dam may be defined as a water-tight wall, enclosing the site on which the pile of a bridge or other structure surrounded by water is to be erected.

Coffer-dams are, of course, constructed of a strength sufficient to bear the pressure of the water from without, which in many cases would damage, or even demolish them altogether, were it not that they are secured by struts, and otherwise strengthened.

The coffer-dam of which Fig. 33 is a section, is one of the simplest used; it consists of a double row of piles, *a*, *a*, united by the head-piece, *b*, the rows of piles being kept at equal distances from each other by cross-timbers, *c*, which, as will be seen in the illustration, act as a cramp in preventing them either spreading outward, or being pressed inward.

Walls of planks, *d d*, are next attached to the inner sides of the piles, the internal space being then rammed with clay, &c.

In drawing this and the future examples, the students are reminded that they are arranged progressively, and that as the subjects increase in difficulty, additional care and accuracy are required. Again they are urged not to be content with their work being *nearly* right. To carpenters and joiners this accuracy is especially important, for the different parts, got out by separate workmen, must, when required, fit exactly to each other, and this would not be the case if either one of them had been careless or inaccurate. This exactitude is only to be obtained by accustoming yourself, from the very outset, to measure with care, and to draw your lines exactly through the proper points.

Fig. 34 is the section of a much stronger coffer-dam, which is so constructed as to preserve its firmness throughout its entire height. This consists of three rows

of piles, *a b c;* the two rows nearest the water, *a* and *b*, being of the full height of the coffer-dam, and the third, *c*, being half the height. These piles are placed at certain distances apart, and are united at the top and at a point just below the middle by cross-timbers, d^1, d^2, placed horizontally on each side of the piles, and attached by being notched on to the piles; an iron bolt passing through all three timbers. The outer row of piles are connected in a similar manner by the cross-pieces, *e*, which are on a level with the rails, d^1 and d^2. Resting on these, timbers, *f*, are laid across in pairs—that is, one timber on each side of the piles, so that each pair grasps the piles, and also the strut between them; bolts tightened up by means of nuts passing through all three. The transverse pieces at the top of the long piles rest on the longitudinal joists, and are in this example shown notched down upon them, for the purpose already explained in the previous study.

The student must now be reminded that up to this stage the construction is a mere skeleton, the piles being six or eight feet apart. This space is filled in by *sheet-piling*—that is, piles placed in a *sheet* or wall. These are narrower than the true piles, and are driven down between the longitudinal cross-pieces or walls, so as to render the whole construction complete.

This hollow wall is now to be filled in with clay, puddle, &c., and the water having been pumped out of the site enclosed by the coffer-dam, the ground must be dredged, and if required a bed of béton* must be laid down on which to erect the intended pier or other structure.

The following practical hints by Mr. Dobson are quoted for the instruction of the student:—"Leakage between the puddle and the surface of the ground will generally take place unless all the loose, soft, or porous surface-soil be carefully removed by dredging before the puddle is put in. This dredging may be done before or after the piles have been driven. Leakage through the puddle-wall itself may arise from various causes, but may generally be prevented by careful work, and selection of good materials. In the first place, the piles should all be

* *Béton*. A kind of concrete, which, owing to its composition, has the property of hardening under water. See "Building Construction," page 23.

fitted to each other before driving, and should be truly and carefully driven; next, the framing and strutting should be sufficiently strong to prevent any straining or movement under the varying pressure to which the dam may be exposed by alternations in the height of the water; and lastly, the material used for the puddle should be such as will settle down into a solid mass, and should be carefully punned in thin layers so as to secure that no vacuities are left in any part. For this reason it is desirable, when the piles have been driven between the double wallings, to remove the inside walls after the piles are home, as any projections of this kind increase the difficulty of punning the puddle. In order to resist the evil effects which might arise from the swelling of the puddle, the inner and outer rows of piles are usually connected with iron bolts passing through the piles, and secured by nuts, with iron plates and large wooden washers to prevent the former from being drawn into the piles by extreme pressure. These tie-bolts are often found to be very troublesome sources of leakage, as the water soaks in round the bolt-holes, and it is difficult to keep the puddle from settling away from the bolts and leaving a channel for the passage of water through the dam."

With this information as to the construction of the coffer-dam, the student will not, it is presumed, require any instructions as to copying the example; and he will (as has been already mentioned) do well to draw the various parts in precisely the same order in which they have been mentioned in the description.

WOODEN BRIDGES.

Wooden bridges may be looked upon as the origin of all other constructions for crossing water or roads, whether of stone or iron; for it seems natural to suppose that in the earliest times the simple method of throwing a plank across a stream may have been adopted—in fact, the falling in that position of a tree on the bank would have suggested such an expedient.

A plank placed across from one bank of a stream to the other is, then, the most elementary form of a timber bridge; it is at the same time the most perfect, and the principle on which it is suspended, or kept in its proper

position, is worthy of consideration. "For," says Mr. Peter Nicholson, "we may learn how to construct the best and most advantageous kind of bridge suitable for immense spans from this unpretending and apparently unpremeditated contrivance."

When a strong plank is thus laid upon two supports that part of it which lies midway between them has to sustain its own weight, and that of anything crossing over it, by the cohesion between its particles—that is, by the power with which the atoms or fibres of which it is built up, cling together; for as that part of the plank has nothing to rest upon, it will be clear that it will have a tendency to break somewhere between the supports when the strain upon it exceeds its strength.

But, owing to the cohesion of the particles, which attracts them one to another, such a plank cannot snap asunder with absolute suddenness, because the cells of which timber is formed are lengthened out into fibres or hollow threads, and these are so interwoven one with another that one particle or atom of the material will not readily be separated from its fellow as long as such material remains in a sound state.* This being the case, the weight upon the beam will cause it to bend, or what is technically termed to "sag," and it is to prevent such bending extending beyond a safe amount of elasticity that the efforts of the constructor of wooden bridges are mainly directed.

Absolute construction does not come within the province of this manual, but, as already stated, the more acquainted a man is with the principles involved in what he is doing, the better will he do his work, and certainly the more interest will he take in it; and therefore, although nothing like a scientific treatise would be in character with the object in view, it is hoped that the following notes on wooden bridges, their history, and peculiarities of construction, may be of interest to those who are now, or who may at any time become, engaged in such works.

It will be easily understood that when a plank is laid across from wall to wall, and a weight is placed on any

* For an account of wood, and how it is formed, see "Our Houses," and "The Uses of Plants," Cassell's Primary Series.

part of it, it bends, because the particles of which it is formed are pressed close together on the upper side, whilst on the under side they are drawn out. If across a plank so placed you had previously drawn lines exactly corresponding with each other, you would find that when a weight is placed on the plank the lines on the lower will be further apart than those on the upper surface. Thus you will understand that two forces are acting on the beam at the same moment, for the upper portion is subjected to a *compressing* force, whilst a tensile or *stretching* force is acting upon the lower side.

It is the strength with which these two forces counteract each other that constitutes the rigidity of timber, and it will be evident that there must be some intermediate plane between the upper and lower surfaces of the beam in which the two opposite contending forces will meet, in which, of course, neither will preponderate. This is denominated the *neutral plane*, and will be differently situated according to the thickness of the beam, and the power of cohesion which is possessed by the fibres of the various kinds of timber.

In looking back to the early history of wooden bridges, we shall find that where rivers were broad and their channels deep, it would be impossible to cross them by single beams of timber. In such cases a timber framing or scaffolding would be formed in the bed of the river by driving piles, or a pier might be formed of stones or other materials. On these, beams of timber would be placed with one extremity resting upon the pier, and the other on the bank of the river, or on an abutment raised at the water's edge, and upon several piers in the water, as the case might be.

Where the distances between the supports were too great for the dimensions of the timber forming the roadway, the main beams were propped up by struts projecting from the sides of the piers or piles, which were sometimes made to meet in the centre; or if that was not practicable, on account of the distance between the supports, they could each be made to sustain the beam, either by running directly to it from the abutment at about an angle of 45°, as in Fig. 35, or a cross-piece, on which their ends should abut, be placed between them and fastened to the under side of the beam, as in Fig. 37.

These struts or stays were then multiplied and disposed in various ways, until at length a rib or arch of timber was formed to support the roadway, while the spandrels* were filled up with struts and ties to resist compression.

The ribs of bridges constructed in this manner were composed of frames, the lower portion of which form segments of circles, frequently made up of several pieces of wood placed immediately over each other and joggled together, so arranged, however, that their ends should break joint. To these circular arcs, or polygonal frames, upright pieces were attached, either by bolts, mortises, or iron straps, by which the weight of beams supporting the roadway was sustained at intervals, and so disposed as that each part might, as far as possible, conduce to the strength of the whole.

I am indebted to Mr. Nicholson for the following historical notes as to timber bridges, which I give in order that the student may glean some intelligence as to what *has been* done—the best possible guidance as to what *may be* done. The extensive use of iron in tubular, girder, and suspension bridges has in modern times superseded, in a great degree, the use of wood, but not entirely so, and as the principles are applicable to so many other timber constructions, no apology will be necessary for describing some of them, especially as they constitute, both in their complete form and in their details, such excellent studies in drawing for all those engaged in wood-work.

The "Pons Sublicius" was the first bridge ever built across the Tiber. It was at first constructed of timber in the reign of Ancus Martius. *It was put together without either bolts or ties*, so that it could readily be taken asunder, and was built for the purpose of connecting together the Aventine and Janiculum hills.

The bridge over the Danube, by Trajan, is almost one of the oldest timber bridges of which we have a detailed account.

It was supported on *twenty stone piers, which were 150 feet high and six feet broad.* On these were framed

* *Spandrel.* The irregular triangular space bounded on one side by the curve of the arch, on the second by the vertical, and on the top by the horizontal lines forming the sides of the angular space in which an arch is contained.

timber arches, each 170 feet span, and formed of three concentric timber rings bound together by radiating pendants. These, together with the arches, supported the longitudinal beams on which the flooring joists were placed across the bridge.

The timber bridge of Schaffhausen, built over the Rhine by Ulrick Grubenmann, was remarkable for its ingenious construction It consisted of two openings, one of 170 feet span, and the other about 190. Its abutments and centre pier were of stone On these were laid a kind of compound beam formed of three rails or walings, each of which consisted of two longitudinal beams bolted together and toothed into each other so as to be perfectly united; these were supported by an infinity of struts, kept in their places by vertical binding pieces, *all tending to transfer the thrust to the supports* of the bridge. It was roofed in for the ostensible purpose of protecting the timber, but there can be no doubt that the roof added greatly to its strength. This bridge (which was demolished in the year 1800), and others designed by the brothers Grubenmann, were, in fact, timber tubular bridges. A Swiss bridge of this kind forms a study for drawing in Fig. 57.

The timber bridge of St. Clair, over the Rhone at Lyons, has seventeen openings, the centre one having a span of forty-five feet, and the others diminishing towards each bank. This bridge has a roadway of about thirty-six feet, which is supported upon piers, each formed of thirteen piles arranged in a single row, running parallel with the banks of the river. On the top of these piles a sill was framed, and longitudinal timbers were made to bear over the head of each pile, and upon these the flooring of the bridge was laid.

The bridge of Grenelle, over the Seine near Paris, built by M. Mallet, consists of two equal and symmetrical bridges, separated by an intermediate piece of dry ground; each of these is formed of three timber bays of eighty-two feet span, *supported upon two abutments and two piers of masonry.* The width of this bridge is nearly thirty-three feet. The ground in the centre measuring eighty-five feet, the whole bridge, reckoning the entire distance from the abutments on either side of the Seine, is 632 feet long.

All the foundations were built on piles, upon which a planking was laid.

These foundations were formed by means of coffer-dams, which at low water was not more than five feet deep. A bridge similar to this was built over the Seine at Iory in 1828.

Besides these, which are merely mentioned as well-known specimens, there is an almost endless number of wooden bridges erected throughout the world, amongst which may be named that at Trenton, in America, of 180 feet span; a bridge over the Tees, 150 feet span; the bridge of Neuecetringen, in Bavaria, 102 feet span: that over the Necker, 210 feet span; the bridge of Bamberg, with an opening of 206 feet, erected by M. Wiebeking, an engineer who has constructed an immense number of timber bridges; the bridge of Feldrick, with a span of 65 feet; the bridge of Zeto, built by M. Coffinet, with a span of 125 feet; besides several put up by the celebrated M. Perronet (whose name has been already mentioned in "Building Construction," page 91).

Before giving some examples for drawing purposes, acting upon my often-repeated wish that my readers should consider drawing as a mental as well as a manual exercise, I ask their attention to the following principles of construction.

Timber bridges are either supported upon piers and abutments of masonry, built on the solid foundation of the ground, or on a platform constructed upon piles driven into the earth, or they are supported upon piers formed upon one or more rows of piles driven in a line with the road or river passing under the bridge. There are almost an infinite variety of ways in which such props or piers may be made. It is, however, usual to drive the piles about a yard apart, from centre to centre, and to bolt capping-pieces or walings to the top of such piles, and either filling up the spaces between with large stones laid dry, or else grouted with mortar. On this the masonry for the supports should be placed, or a timber framing, if desired, or else the piles may be carried up to the height of the roadway, being kept in their places by walings and diagonal pieces, bolted on each side of them. These piles should be about a foot square, and when they are driven in salt water or in tidal rivers, their

surfaces, up to high-water mark, should be sheathed with copper, or otherwise protected from the ravages of the worm.

At each end of the piers in the water, in cases where several rows of piles are driven, a sort of cutwater should be formed, in order to ward off heavy bodies, such as floating trees, ice, &c., and prevent them from injuring the superstructure (called in German constructions, "Eisbrecher," or ice-breaker). This is usually done by driving one pile by itself in advance of the rest, or by forming what is called a "dolphin" at each end of the pier.

The piers and abutments should, of course, be made in every case sufficiently strong to resist the thrust of the arch. In cases of small foot-bridges, where even the distance between the supports should be as much as twenty or thirty feet, longitudinal scarfed girders may be laid upon the caps of the piles. Under such circumstances, as we have seen, there is nothing but the weight or perpendicular pressure to be provided for; and the same may be said of timber bridges of greater width, for roads, and even for railways, provided the distance between the piers does not greatly exceed ten or fifteen feet. Beyond that opening, however, bridges are usually sustained by struts or tension-rods, or the roadway timbers are trussed so as to exert an oblique pressure upon the supports; indeed, in all instances of the kind, where the bays are formed upon the principle of compression or tension, the piers must be so formed as to counteract the tendency constantly exerted to force them out of their perpendicular position. This must be done either by making them of sufficient weight and strength to overcome any force that may be exerted against them, or else to counterbalance the efforts of one bay or arch acting in one direction, by a similarly acting arch or timber frame exerting a like force in a contrary direction. The former of these methods is used in the abutments of a bridge, whilst the latter is invariably adopted with respect to piers.

The roadway of timber bridges is usually a flooring of boards laid upon the joists, for, in cases where sand and stones are employed, it is found that their weight, together with the humidity they engender, causes the timbers of

such bridges speedily to decay. This, however, is far from being a general rule, and many splendid erections of this description are rapidly being destroyed, owing to a want of attention to this important particular. Some have proposed to cover the surface of the roadway with lead, iron, copper, &c., but the increased expense will be a great obstacle to their frequent introduction. Wood pavement forms an excellent covering for timber bridges, and is highly recommended by various engineers.

The parapet, or hand-rail, of these bridges is frequently of wood, or it may be of cast and wrought iron. Now, however, that it has been shown how important an addition to the strength of a bridge the sides of a beam are, and that it acts usefully in the direction of its depth, if it has only sufficient breadth to prevent its yielding laterally, it ought in every case be made available to sustain the bridge, in addition to its present purposes of ornament and protection.

Fig. 35 is one of three bays of a wooden girder bridge, which is the simplest class of such constructions, consisting merely of beams laid across the stream and supported by piers formed of wooden framework, from which struts spread out on either side, which extend the bearing effect of the piers, and so diminish the length of the girder which is left unsupported.

In drawing this example first get a horizontal line, to form the top of the elevation of one of the cross-pieces, which, resting on purlins, clamp the piles forming the piers between them.

As this portion of the structure is shown on an enlarged scale in Fig. 39, the lettering here given will apply to that illustration. *a' a'*, then, is the front elevation of the pile against which the struts, *a*, are firmly bolted, and on to these the purlins, *f*, are notched. These struts, too, are halved on to the pile at their upper ends, so that they clamp it between them. This arrangement is shown in Fig. 40, which is the side elevation.

Returning, then, to the drawing, Fig. 35, the horizontal line drawn is to be the top line of the cross-beams, which in Fig. 39 is lettered *c*. Now, in the front elevation these are seen in section (as in Fig. 40); but, as you will observe, you will require the same height in the cross-section, Fig. 36. Draw this line of indefinite length at

once, and this system of projecting one view from the other is to be carried on throughout, as thereby much time will be saved, and certainly greater accuracy ensured, for it is by far easier to continue a line at once than to "piece" it afterwards.

Next draw a second horizontal line under the other, at such a distance from it as to give the lower edge of the cross-pieces, *c*, and then, having drawn the irregular line

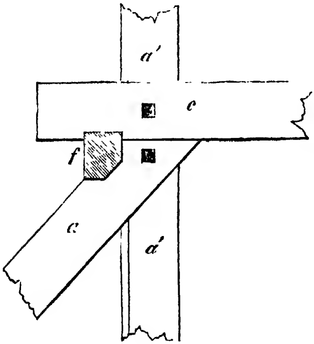


Fig 39.

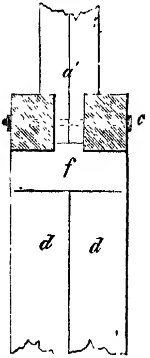


Fig. 40.

representing the bed of the stream, draw the vertical lines, which will form the sides of the struts, *dd* (seen in *front* elevation).

Now, on referring to the cross-section, Fig 36, it will be seen that precisely this same arrangement exists in regard to the middle pile—namely, that it is clamped between two cross-pieces, and against these two struts abut. These cross-pieces are shown in section in Fig. 36, the struts being merely represented by the three perpendicular lines under these. They are, however, shown in elevation in Fig. 35, where their effect of adding to the steadiness of the frame will be evident.

The foundation of the pier being thus completed, next draw the uprights and the cross-timber resting upon

them. This is shown in its full length in Fig. 36, and in section on each of the piles in Fig. 35. The upper line of this cross-timber will, of course, form the lower line of the main girders resting upon the cross-pieces. Now draw the upper edge of these girders, which, of course, are seen in elevation in Fig. 35, and are represented by seven shaded squares in Fig. 36, these squares representing the sections of the seven ribs, which will thus be seen to be made of square timber. Each of these girders rests immediately on a pile, so that the bridge is supported by seven ribs. You will now draw the struts, and as these are here placed at an angle of 45°, you can use your set-square, or, of course, you can find the exact inclination, whatever that might be, by measuring the distances of the upper and lower ends of the strut from the right angle. These struts are now to be added to the cross-section (Fig. 36), from which it will be seen that they are narrower in this direction than in the other. The horizontal line forming the top of the flooring of the bridge is now to be drawn, and as these planks, of course, run at right angles to the girders, their ends are shown in Fig. 35, whilst their length is shown in Fig. 36.

Fig. 37 is an example of a bridge in which the struts

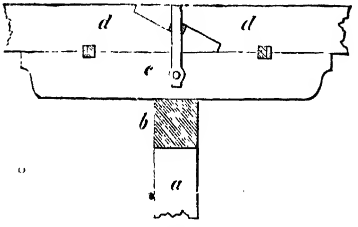


Fig. 41.

abut against centre-pieces, placed on the under side of the girders, as referred to in page 34. They do not, however, touch these centre-pieces directly, but cross-timbers, the sections of which are shown in the elevation, are placed as end-ties, and against these the struts abut.

The heads of the piles are united by a waling-piece, on which, over each pile, a saddle-piece rests, supported by struts. This gives a much broader surface on which to rest the girders, which are scarfed at this point.

In drawing this bridge, the system is precisely similar to that adopted in the former example, and, therefore, no further explanation need be given.

Figs. 41 and 42 are examples of scarfing the girders, and of the methods of supporting them. The latter

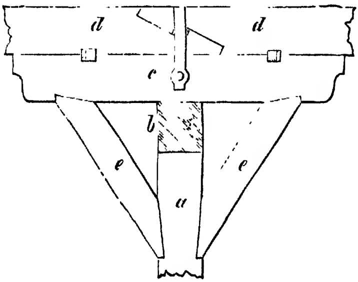


Fig. 42.

method is that adopted in the preceding study. The subject of scarfing has been already treated of in "Building Construction."

Fig. 43 is an illustration taken from a five-bay girder bridge in Germany. This is supported on stone abutments and piers, the bearing of which is extended, first, by two saddle-pieces, the upper projecting below the under one, which, in its turn, projects beyond the pier. Next, the bridge itself is formed of double girders, one above the other. Now, the upper one is supported by struts, which are shown in the longitudinal section (Fig. 44); and as cross-timbers passing transversely beneath the lower girders are bolted through to the upper ones, the lower girders may be said to be suspended from those above them.

From Fig. 45, which is a transverse section on the line

a b, it will be seen that the footway is raised to a higher level than the roadway by means of square timbers resting on transverse beams. The roadway is laid upon round timbers, which are extensively used in Germany.

Although only one bay is given in the example, the student is advised to draw more than this (of course, to a larger scale), as the practice thus obtained will be of great service to him.

In commencing, rule a straight line for the bed of the river, and draw the foundations and embankments. Next erect perpendiculars on the middle of the foundations, to act as centre-lines for the piers. On these perpendiculars, mark off the heights of the cornice and capping of the piers and abutments, and draw the required horizontals; on these, mark off the respective widths from the centre-line, and complete the piers both above and below the capping.

The profile (or side view) of the abutment now requires our attention, the next task being that of drawing it at the same slant as the sides of the piers. Now, in this bridge the space between the abutment and the pier is the same as that between any two of the piers; therefore, measure that distance from *centre to centre*, and from the central perpendicular of the last pier mark off this distance on either of the horizontals, and through the point thus obtained draw a perpendicular, which will be to the profile of the abutment as the central perpendiculars are to the piers; therefore, proceed in the same manner to set off half the width of the pier on the horizontals, and thus complete the abutments.

The double saddle-pieces resting on the piers and abutments are to be drawn next, and then the double girders. The hand-rail may now be commenced.

Having drawn the top rail and the standards which divide the length into ten equal rectangles, draw diagonals in each; then the lines forming the cross-struts are to be drawn parallel to these. The longitudinal and transverse sections will not, it is presumed, require further instruction, and we can therefore turn our attention to the next series of examples of hand-rails.

The most simple of these is Fig. 46. In beginning this, it is best to draw the section (Fig. 47) first, as from it, the

elevation of the cornice and of the horizontal bars must be projected.

Having, then, drawn Fig. 47, draw horizontals from the different points in the section of the cornice, *a*, and from the top and bottom of the section of the top rail, *b*.

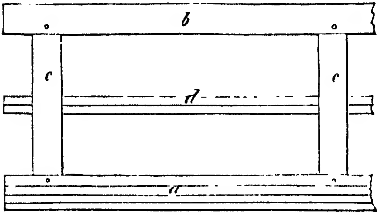


Fig 46.

Fig. 47.

Next draw the standards, *c c*; then from the angles of the square middle rail, *d*, project the elevation, *d*, which will complete the figure.

Fig. 48 is an enlarged elevation of the hand-rail already

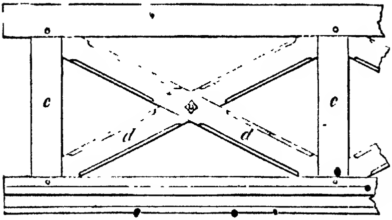


Fig 48.

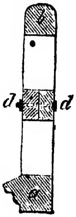


Fig 49.

shown in Fig. 43. Here the section (Fig. 49) is to be drawn first, excepting the part *d d*, which is determined according to the angle at which the struts cross each other. Having, then, projected the elevation of the top rail and cornice from the section, draw the standards, *c c*, and diagonals in the rectangle.

Now let us suppose (as would in practice, of course, be the case) that the struts are to be of a definite width. To set this off accurately, draw a line through each diagonal, at any part, but at *right angles* to it. On these, on each side of the diagonals set off from the intersection half of the width of the struts; then lines drawn through these points parallel to the diagonals will give the sides of the cross-pieces required.

It will be seen that the lines thus drawn will at their intersection form a lozenge or diamond-shape; from the lower and upper angle of this figure, draw horizontals, which will give the section, *d d*, in Fig. 49, and in this the central vertical line will show that the struts in crossing are "halved" into each other, so they are "flush" with the uprights and with the upper rail. The splaying of the edges can of course be done without any further guidance.

Fig. 50 is a hand-rail of a similar character to the last, but the space between the standards is to be filled with two

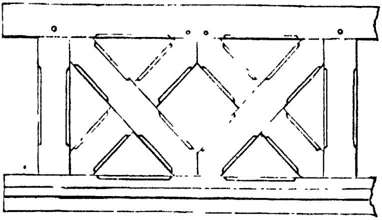


Fig. 50

Fig 51.

pairs of struts at right angles to each other. Now the space is doubly as long as it is wide; therefore divide it into two equal squares, in which draw diagonals. On these, set off from their intersection half of the width of the struts, and draw the lines which form the edges of them; the section (Fig. 51) can then, as in the last figure, be completed from the elevation.

Fig. 53 is a mere trellis-rail, and will be found very

easy to draw; but care is required so that all the interstices may be *equal squares*.

Having drawn the section (Fig. 52), and projected the cornice and upper rail in the elevation (Fig. 53), draw

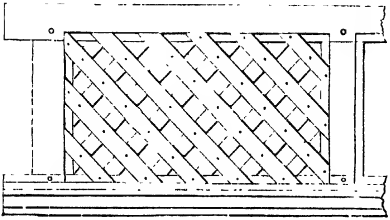


Fig 53.

Fig 52.

centre-lines for each of the cross-pieces, which will be readily accomplished with your set-square of 45°. On each side of the intersection set off half the width of the pieces, and draw the lines; it will thus be seen that this is a repetition of the last figure, but with a multiplication of parts.

DRAWING FROM OBJECTS (*continued*).

Agreeably with the plan already laid down, to practise freehand concurrently with linear drawing, the following figures are given as examples of an object which is so nearly flat that it can be rendered by its outlines only, and another which gives a perspective view of a solid form.

Fig. 54 is a drawing of a tool with which the carpenter will be well acquainted; but it often happens that although we may see a thing daily, we have never noticed the peculiarities in its form which may strike a casual observer.

This habit of observation is one of the beneficial results of mental training, and no instruction is so likely to induce it as drawing; for a man who accustoms himself

to draw from objects, will, in the old-fashioned words, "walk through the world with his eyes open," and every day, nay, every hour, will add to his stock of information, and of his power of delineating the objects he sees. To workmen this is especially important, and practice in drawing tools will be both interesting and useful.

In the figure now before us, the long oblique line, *a b*, forming the back of the saw, is to be drawn first, and then *b c* at right angles to *a b*. At *a*, a short curve will lead to the line *d*, which is a continuation of the back, thence the line turns to *e*, forming the end of the saw. From *e* draw a fine line on which to rest the edge, and on this set off the distances of the points of the teeth; on these points the short lines forming the front edges of the teeth are to be drawn. It is advisable that these should all be drawn first, as it is then easier to see whether they are all at equal distances, or parallel to each other, or not. When these are satisfactorily done, the back line of each tooth may be drawn.

The handle must now be added, and this requires some little care.

Carry on the line from *b* in a curve downwards, and then the eye must direct you in following the form until you come to *g*. Returning to *f*, draw *f h*, and follow the curve to *i*; next, the under side of the handle, *i j*, then the curve *g j* will complete the external form of the handle.

Now return to the point *i*, and carry the curve round so as to form the inside of the handle. The screws are to be drawn next, and no workman will require to be reminded that these must be placed *in*side the line *b c*; in fact, it was to make sure that the screws should be rightly placed that the whole line *b c* has been drawn, whilst only the portion *i c* is required.

Now, all saw-handles are not precisely alike, and further, their edges are beveled off, so that at *f h i*, &c., double lines would be seen. All this is, however, omitted here, so as to keep the example as simple as possible. When, however, this is mastered, the student is advised to make a drawing *from his own saw*, and having sketched the general form as in the present figure, to fill in any detail he may observe.

But he should also attempt to draw it in some other

position; for instance, hanging by the handle from a nail in the wall.

Whilst making such a sketch, the paper must be kept perfectly straight in front of the student; but when the form is completed, he should turn it so that it may be in the position of that in Fig. 54, and he will then possibly see many points requiring correction. Still, it is necessary that he should become accustomed to sketching objects in any position in which they may be placed, and this will soon be accomplished by practice and perseverance.

The object of the next example is to teach the method of drawing the steps shown in Fig. 56; but before that is attempted, it is desirable that the student should have an exercise in the accurate division of spaces by straight lines.

Such a practice is given in Fig. 55.

In commencing this figure, draw the square, A B C D, and in this bear in mind that a square must have four *equal* sides, and four *right* angles. This having been accomplished, draw the lines E F and G H, thus dividing the square into four equal squares; be sure that they fulfil these conditions; then draw the lines *g h*, *i j*, *k l*, *m n*, by which the square will now be divided into sixteen equal squares.

Now let us suppose that this figure is the end view of sixteen square bars, thus placed; then it will be seen that if the bars 1, 2, 3, 4, 5, 6 were removed, the end elevation of four steps would remain. The profile of these steps has been drawn in a rather heavier line, and the student will do well now to practise this form without the aid of the complete square.

Fig. 56 is the further working out of this study. Having drawn the end elevation of the block of steps, mark your point of sight, which in the present view will, of course, be on the left side, and higher than the object.

Now it will be remembered that all lines which are a right angles to the plane of the picture converge (that is, draw together) to the point of sight; and as the end elevation is parallel to the picture-plane, the long edges of the steps which are at right angles to the end must be at right angles to the picture-plane also. Therefore, from the points *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, and *i*, draw lines to the point of sight (not shown in the figure); then, having decided on

the apparent length of the steps, draw the perpendicular at *m n* and the horizontal *n e*; proceed in this way until the top is reached, carefully observing, that as the distant end elevation of the steps is in reality the same in form and size as that in the front, and that it is parallel to it, it will therefore remain in every respect similar in shape, though diminished by distance. You must be careful, therefore, that the lines forming the end are perfectly vertical and horizontal to correspond with *a b*, *b c*, &c., in the end elevation which is seen.

LINEAR DRAWING FOR CARPENTERS
(*continued*).

We now return to the study of Linear Drawing, and the carpenter will still gain practice by drawing another wooden bridge or two. Not because these are now as much used in this country as they were in times gone by, but because the principles of their construction convey so much instruction, which will be of service in the subsequent section on roofs. And further, in these days of railways and emigration, some knowledge of the construction of bridges of a material which is so generally available cannot fail to be of service.

Fig. 57 is partly an elevation and partly a longitudinal section of a covered wooden truss-bridge, such as is frequently used for passengers to pass from one platform of a railway to the other.

Here it is necessary briefly to remind the student of the action of a king post—viz., that when the lower ends of the principal rafters (two strong timbers, *which together* are longer than the space to be bridged over) are mortised or otherwise fixed by their lower ends to the tie-beam, the upper ends abutting against the head of the king-post, this acts as the key-stone of an arch, and being lengthened, the tie-beam is bolted or strapped up to it. This principle, illustrated by the necessary diagrams, has been already treated of in "Building Construction," and will be further worked out in connection with roofs.

In the present example the tie-beam is built up of two equal timbers, which are scarfed or toothed into each other, and the king-post, being also double, clasps the tie-beam at the bottom. Underneath the tie-beam a

transverse bearer passes from one king-post to the other, and these being screwed up by means of screw-bolts, the tie-beam is drawn up into a curve. The principals, too, are made up of two equal lengths.

In addition to this, there are queen-posts, which are supported at the top by means of a collar-beam and struts, and to these, bearers passing transversely under the tie-beams are bolted, like those under the king-posts. There are also intermediate suspending posts, from which bearers are not suspended, but to which bolts pass through the tie-beams.

The half of Fig. 57 which is given in section, will show the manner in which the planks forming the floor of the bridge are laid, and the longitudinal girders resting on the transverse bearers are shown in the section (Fig. 58), in which the simple roof timbers are also shown.

Fig. 59 is a horizontal section, showing the diagonal straining-pieces between the bearers.

A few instructions on the method of drawing this subject (Fig. 57) will now be given.

First draw the piers, and a straight line uniting their springing points.

Bisect this line, and in the perpendicular, set off from the intersection the height of the curve from the horizontal line. There will then be three fixed points—viz., the two springing points, and that in the perpendicular.

Now it will be remembered that if these points be joined, and the lines uniting them be bisected, the intersection of the bisecting lines will be the centre of the circle of which the arc is a part. This problem is worked out in Fig. 16 in "Linear Drawing."

Having, then, thus found the centre, describe the arc forming the under side of the tie-beam. The arcs under this are to be drawn with the same radius, moving the centres a little lower down on the perpendicular.

The tie-beam is rather broader in the middle than at the ends, and therefore the upper arc must be struck with a rather shorter radius, the centre being slightly higher than that from which the under side was drawn; from a point half-way between these two centres an arc must be struck, exactly between the upper and lower edges of the tie-beam, and on this the toothing of the scarf is to be drawn.

Now proceed to draw the king-post, measuring half its width on each side of the central perpendicular, then the principal rafters, the collar-beam, and the longitudinal joist above it; then follow the queen-posts, the suspension-pieces, and the ends of the bearers.

The foundation for the fronts, and the fronts themselves, are now to be drawn; then the ridge and the rafters.

After this, the boarding of the sides of the bridge is to be filled in, and any other detail which may not have required separate mention.

Figs. 58 and 59 are too simple in their lines for the student to need any instructions as to the mode of drawing them; he is simply advised to draw the different parts in the order in which they have been explained in the elevation.

Fig. 60 is a side elevation of a small bridge constructed on the "bow suspension truss" principle.

Here the bow, consisting of a single beam, is mortised into the ends of the tie-beam, which are in their turn strengthened by saddle-pieces, bolts passing through these saddle-pieces, the tie-beam, and the bow

At regular intervals perpendicular posts are placed between the tie-beam and the bow.

Underneath these are placed the transverse bearers, bolts passing through these, the tie-beam, the perpendiculars, and bow. On the bearers timbers are laid parallel to the truss, and on these the flooring of the bridge rests. This arrangement will be clearly understood on referring to the section, Fig. 61.

In commencing to copy this example, draw the horizontal line which forms the tops of the abutments, and then add the oblique lines representing the imposts.

Next draw another horizontal line, and between this and the last, mark off the widths of the ends of the cross-timbers which act as wall-plates, on which the trusses are to rest.

This horizontal will also give the lower side of the saddle-pieces, and the horizontal which will give the top of these will also form the under side of the tie-beam, the upper side of which, and the ends of the saddle-pieces may now be drawn.

The points at which the outer arc of the bow meets the upper line of the tie-beam are next to be marked, and the height of the bow set off on a central perpendicular. From these three points, the centre from which the arc is struck will be found in the manner already mentioned. The internal arc and the mortises at the ends will then complete the bow.

Having divided the space on each side into four equal parts by dotted perpendiculars, set off on each side of these half the thickness of the uprights, draw the ends of the bearers, the rail-bolts, &c.

The section is so very simple that no further instruction connected with its delineation is deemed necessary.

It can be well understood that the system of forming the bow of a single timber must be limited to bridges of small span, and an improvement was effected in this respect by the introduction of a system invented by Philibert de Lorme, a celebrated French architect.

This system was not new, its author having proposed it in the sixteenth century, and it had been used more or less from that period; but it seems to have been first applied to bridges in that over the Weser, near Minden, in Westphalia, in the year 1800.

The De Lorme system will be fully described and illustrated in connection with "Roofs," in the construction of which it has been principally used; it may, however, be briefly stated here that it consists in building up the bow of separate pieces of timber placed *edge-wise*, and united in the manner called break-joint—that is, the joints in the pieces of each layer of timber composing the bow are alternated, so that those in the one are over the whole part of the other, nails and bolts passing through the complete thickness.

Fig. 62 is the elevation of the bridge over the Weser above alluded to. The bow, built up as described, abuts against oak blocks, toothed and bolted on to the ends of the tie-beam. From the bow, transverse bearers are suspended by means of seven iron rods, placed as in the drawing, and on these the beams supporting the roadway rest.

It is deemed necessary, in relation to the drawing of this example, to remark that the lines forming the joints (that is, the ends of each piece of timber) must be radii

of the circle of which the arc is a part. In the present instance, the arc is that subtending an angle of 60°; therefore, having drawn the tie-beam, and marked the points at which the under side of the bow meet it, with distance between these two points as radius, describe arcs, cutting each other in a point below, which would be the apex of an equilateral triangle ("Linear Drawing," Fig. 13, page 12), and from this centre the arcs are to be described.

The disadvantages connected with the De Lorme system are, first, that the stiffness of the span must depend mainly upon the natural strength with which the fibres of the wood adhere to each other; and as this is of course limited, it is necessary to construct the curved rafters of greater width than would otherwise be required, in order to ensure them against the strain to which they may be subjected. Secondly, there is, from the circumstance above alluded to, and from the necessity of sawing the segments out of straight timber, a great waste of material, time, and labour.

These considerations naturally prevented the system becoming very general, and in 1809 an improvement thereon was proposed by a celebrated Prussian architect named Wiebeking, which was in 1817 perfected by Colonel Emys, a French military engineer, which has since been extensively used.

By Emys' system, the arched ribs are laminated--that is, formed of "laminæ" or thin layers of timbers—not placed edge-ways, as in the De Lorme plan, but laid flat on each other, the break-joint system being still preserved, and the planks being held together by iron straps with which they are surrounded.

The whole rib is then confined by its ends fitting into cast-iron shoes bolted on to the tie-beam. Thus, all the fibres of the wood coincide with the curvature of the rib, and thus, not only are they not liable to be torn asunder, but a great amount of elasticity is obtained. As this system has been extensively used in the construction of roofs, it will be further described in the section devoted to that subject, and the attention of the student is now directed to the elevation of one of three arched ribs of a wooden railway bridge (Fig. 63).

Here the tie-beam is formed of double timbers, resting on an additional piece at each end.

The bow is made up of seven layers of timber, united in the manner shown in Fig. 64, which is an enlarged drawing of the middle portion of the truss.

Seven perpendiculars are placed between the bow and the tie-beam, by which the latter is suspended as by king and queen posts. The mode in which the iron bands, nuts, and screws act in such cases has been described in connection with Roofs in "Building Construction."

The trusses are further stiffened by diagonal struts between the perpendiculars. Across the tie-beams of the three ribs the sleepers are placed, on which the flooring of the bridge and the rails are laid.

The piers, saddle-pieces, and tie-beams having been drawn, the arc forming the upper edge of the bow is next to be described. The cast-iron shoes necessarily follow. In the smaller view (Fig. 63), their outer edge is shown as continuous with the arc of the bow; but in working this figure to a larger scale, this should be drawn with a rather wider radius, so that the iron shoes may project to allow for the thickness of the material. As in the case of the cross-joints of the timbers in the De Lorme bow-truss, the third side of the cast-iron shoes and the bands by which the laminæ are clamped together, are radii of the circle of which the bow is a part, and therefore converge to the same centre. This is not, however, the case with the irons by which the uprights are suspended. These plates, which end in screws, are, of course, placed parallel to the posts; at the top a cross-plate unites the screws, on which are washers and nuts. The irons at the bottom of the perpendiculars are similar in character.

When the bow has been completed, the perpendiculars for the centres of the uprights are to be dotted in, and on each side of these half the thickness of the supports is to be drawn. The upper and lower ends of these are, of course, wider than the middle part, the two widths being joined by short oblique lines.

Now, from the points where these oblique lines join the outer to the inner width, and so form a "head," draw diagonals in the interspaces, which will form the centre-lines for the struts. It will be observed that the oblique lines, which form part of the ends of the struts,

are at right angles to their sides. It is presumed that this drawing can be finished without any further instructions.

The student is required, in the first case, to draw Fig. 63 to the size of Fig. 64, and then to repeat the whole figure, making the drawing once and a half the size of Fig. 64. In both of these cases great care will be necessary in drawing the parallel arcs, and he is reminded (see "Projection," page 16) of the purpose of the joint in the inking-leg of the compass namely, so that by bending the leg both nibs may touch the paper, and thus roughness of the edge of the line may be avoided. The lengthening bar will also be needed, and it is then advisable to hold the steel end of the compass in its place with the left hand whilst describing the arcs with the right, for the instrument, thus lengthened, becomes rather unwieldy, and the point is then liable to slip out of the centre.

Fig. 65 is the elevation, Fig. 66 a section, and Fig. 67 a half plan of one of the three arches of the wooden railway-bridge from Paris to St. Germain. This bridge is supported upon, instead of being suspended from, the four arch trusses. These bows are formed of fifteen laminæ, or layers; but not only is the break-joint system carried out in the length, but in the breadth, as will be seen in the transverse section of the bows (Fig. 68). The planks of which the bows are formed are tarred, excepting on the outermost edge, and further, coarse paper saturated with tar was laid between them before binding to the template. When the required curve was attained, the planks were united by strong oak pins, plates of lead being previously inserted to prevent the wood suffering from the stress. The planks are further secured by iron bands, as in the former example.

The ends of the bows abut in cast-iron shoes, firmly fixed in the springings of the piers.

Fig. 69 is the half section of the upper portion of this arch, showing the manner in which the four ribs are connected by iron tie-rods, the longitudinal girders, transverse bearers, the flooring, and the hand-rail.

With this knowledge of the construction of the bridge, the student will not, it is believed, require any information as to the mode of drawing the example, and,

therefore, will be left to apply the instruction he has received in relation to the previous studies.

Fig. 70 is the half elevation of an American timber bridge, by which the Erie Railway is carried over a span of 300 feet. The arch ribs of this structure consist of two separate bows, clamped between cross-timbers, and stiffened by struts placed diagonally.

The bows are constructed of three layers each, with extra pieces above and below at each end, all being, of course, firmly bolted together. These ribs abut against iron plates attached to the rocks, and support perpendiculars. On these, transverse beams rest bearing longitudinal joists, across which sleepers are again placed for the support of the floor-joists of the road.

This construction will be best understood by referring to the section (Fig. 71), from which it will be seen that four such ribs are employed in the bridge, two of which, as in the last example, are placed close together in the middle, the whole being strengthened in a transverse direction by cross-struts.

The longitudinal joists being thus secured on the top of transverse head-pieces resting on the perpendiculars, the bows are braced up to them by means of straining-pieces clamping these and all the other timbers between them. This is shown in the section, from which it will also be seen that each of the three layers in the bows is made of two timbers, placed side by side, each single bow being thus formed of six square beams in the middle and twelve at its extremities.

This being the last study connected with bridges, the student is expected to be able to draw it without any instructions, but is advised to copy it on a much larger scale.

Figs. 72, 73, 74, with its section 75, are different methods used in the abutments of bow trusses.

DRAWING FROM OBJECTS (*continued*).

Returning now to the study of drawing from Solid Forms, certain models will be required, and, as it is desired to inculcate as much as possible the principle of "self-help," sketches of a few are annexed, which any carpenter or

joiner will be able to make for himself. These form a portion of a set * which I have employed for many years past, and which I have found most useful.

It will be seen that the objects represented in Figs. 76, 77, 78, and 81 are cut from a stick of timber three inches square; Fig. 76 being equal to three square blocks or cubes cut from the stick, Fig. 77 equal to two, and Fig. 78 equal to one and a half cubes, whilst the pyramid, Fig. 81, is equal to two cubes in height, but is tapered to a point.

Figs. 79 and 80 are prisms, the ends of which are equal-sided triangles of three inches side. Fig. 79 equals in length Fig. 77, and Fig. 80 equals in length Fig. 78. Provided with these models, place one of the blocks on your left hand (Fig. 82), and, fixing your point of sight on the right, sketch the block according to the instructions given in relation to Fig. 24. It is, however, desirable when the lines E F, E G, and G C have been completed to draw the fine lines A H and F H. Then a perpendicular line, G H, will give a view of the object as if it were a glass box or a wire model, so that the distant lines could be seen.

Place on this, one of the triangular prisms (Fig. 79), and it will be seen that the elementary form of a cottage will at once be built up.

Now the line D E is the perspective appearance of the base of the triangle forming the end of the prism; but it will be remembered that the height of an equilateral triangle is less than the length of the side (see "Projection," Plate XV., Fig. 1), and further, as heights are not governed by widths, no assistance in finding the place for the apex of the triangle will be received from the line D E.

It will, however, be seen by Fig. 83, which is a view of the object when the end faces the spectator, that the apex of the triangle is directly over the middle of the square on which it stands; therefore, draw the diagonals B E and D F, and through their intersection raise a perpendicular. Produce B D, and mark from I the length I J, the height of the triangle—you will thus obtain the point K.

From K, draw a line to the point of sight, which, cutting

* Ellis A. Davidson's Drawing Objects, comprising—1. A Church (ten pieces). 2. A Bridge. 3. A Cottage. 4. A Doorway with Steps. 5. A Garden-roller. 6. A Step-ladder. 7. A Small Ladder. 8. A Field Gate. 9. A Garden Gate.

the perpendicular drawn through the intersection of the diagonals, will give the required apex, I. Join L D and L E, which will complete the perspective view of the triangle.

Draw a horizontal from the bottom of the perpendicular I., and from the point where this cuts the line A H, erect a perpendicular. Draw a horizontal line from I, cutting this perpendicular in M. Draw C M. which will complete the view of the object.

Fig. 83, as already stated, is a view of the object when its end elevation is parallel to the picture-plane.

As in the former study, it is advisable to draw the lower block completely before adding the other, and further, to represent it as if transparent.

The end elevation, then, of the lower block will be a perfect square. On this place an equilateral triangle.

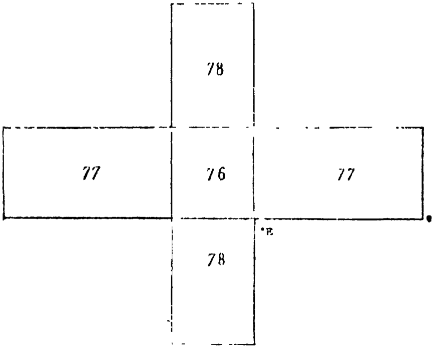


Fig 84

NOTE.—The figures refer to the numbers of the separate blocks in the cut annexed

You are advised to do thus much of this figure when you have completed merely the lower block of the last, in order that you may be able to fix the height of the point K, by observing the height of I J.

Now, in the distant end of the lower block, which is imagined to be transparent, draw diagonals, and through

their intersection erect a perpendicular. From J. draw a line to the point of sight, cutting this perpendicular in N. Draw J N and N O, which will complete the view of the object.

Having thus sketched these simple objects in the manner

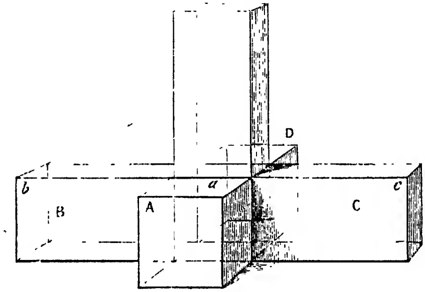


Fig. 85

suggested, the student will, it is hoped, find little, if indeed any, difficulty in drawing them when differently placed, and he is advised to group them, or other similar rectangular forms, and to endeavour to make rapid hand-sketches of them.

We now proceed to further combinations of our models.

Fig. 84.—This is a "ground-plan," which, you will remember, is the shape of the ground covered by any object, and is here given to show you how to place the models which are to form the subject of the next study.

Stand the longest of the blocks (Fig. 76) on its end, and on each side of it, place one of the blocks (Fig. 77), lying on one of their long faces, and on the other two sides place the two blocks (Fig. 78).

Fig. 85 is the view of the models so placed, ar practice already obtained will, it is hoped, hav the student to sketch the group directly from especially as they have already been sepa

The block A should be drawn first

and C, observing that the upper edge, *bc*, of the front of these, is but a continuation of the back line, *a*, of the upper surface of the block A; and this remark will, of course, apply to the bottom edge of the blocks. The edge of the block A produced will also give the corresponding edge of the block D.

Now, it will be seen from the plan that when these four blocks are arranged as directed, a square space is left in the middle, and on this the highest of the models is placed. Thus, then, the point E in the plan is not only the plan of the perpendicular which marks the junction of the models A and C, but also of the edge of the long block, the other edges being obtained from the corresponding points in the sketch.

With these few hints, the group is left in the hands of the student, the object being *not* to teach him to *copy* the diagrams, but to work directly from the models, *applying* the principles which have been laid down.

Fig. 86 is a view of a church formed from the ten blocks. In drawing this, proceed precisely as in the last figure, until your drawing has reached the stage delineated in Fig. 85. Then add the triangular prisms, which, it will be seen, form the roofs of the nave and transepts; then complete the whole by adding the pyramid, which will form the spire. Some little care is required in fixing the apex, or point, of this pyramid. Draw diagonals in the upper surface of the block which forms the tower, and at their intersection erect a perpendicular. The point will be on this, and must be fixed at the height required. This is shown in Fig. 87, which gives a view of a pyramid seen from below, as, owing to the height of the model, the diagonal would not be seen in the present view.

It is not intended to enter here into the subject of the projection of shadows, which will be fully treated of in another volume of this series; but as a simple broad shade assists in "bringing out" a sketch of a solid form, a few hints are given to guide the student in shading from models.

It must, however, be strongly impressed on the student that no attempt to shade should be made until the outline has been examined in every way to ensure its correctness; and that *no amount of shading will make up for bad drawing*, whereas a bold and clear outline may in most cases be made independent of any shading at all.

Only *one* light must be used when you are shading from a model, and this you will place in the manner which will best serve to bring out the form of the object by throwing some portion of it into the shade.

Now, if you place one of the rectangular models near the opposite edge of the table, and place a candle near the edge at which you are sitting, and further on the left than the model, then the light will be prevented falling on the *right* side and back of the model, whilst the front and left side will be fully exposed to the rays; the back and right side will then be *shaded.*

But, in addition to the solidity of the object keeping the light from falling on the sides of the model which are not opposite to it, it also hinders the light from falling on the table, which, near the back and right side of the model, will be quite dark. This darkness is called the *shadow.* The distinction, then, between these two terms is, that any part of an object which does not receive the rays of light is said to be *shaded;* but when this object prevents the light falling on another object, the part of that second object which is then darkened is called the *shadow*, and you may take it as a general rule that *shadows* are *darker* than *shades.*

Thus then, the side of the spire and tower, the side of the transept, and the gable-end of the nave are shaded, whilst the *shadow* of the tower falls on the roof of the nave, and the shadow of the transept falls on the adjoining wall of the nave.

These tints are to be laid on with a rather large brush containing thin colour--either Indian ink or sepia, the shadows to be afterwards darkened by another wash.

Be careful to observe that the shadows must not have a hard edge, and, therefore, this must be softened off with your water-brush before the colour is quite dry.

LINEAR DRAWING FOR CARPENTERS

(*continued*).—ROOFS.

The general principles of Building Construction having been treated of in a separate volume, it is not deemed necessary to follow the exact order in which a building would be erected, the object of the present

manual being improvement in *drawing*, whilst at the same time the principles of the construction of the subject of the study are given, so that the student may not simply learn to copy *lines*, but may understand the language of which such lines are the words and sentences.

The various methods of construction used in timber bridges bear such an analogy to those of roofs, that I have deemed it advisable to follow up the subject whilst the principles of trusses, &c., are fresh in the memory of the student.

Before, however, entering upon the elucidation of the series of drawing examples, a brief review of this branch of the subject is necessary. For this I am indebted to Mr. Peter Nicholson's excellent standard works, which the student will do well to consult when the object of the present little book shall have been attained—viz., the opening up of the subject in an elementary manner, so as to enable the beginner to work with profit from more complex works. Some of these remarks have already been given in "Building Construction," but are here repeated to save referring, and so as to render each volume as complete in itself as possible.

The term roof seems derived from the Saxon word "hrof," or, perhaps, a contraction of the German words "Hier-auf" (upon here), and, as is well known, means the cover or top of a building, generally consisting of two sloping sides, though occasionally of other figures.

The ancient Egyptians, Babylonians, Persians, as well as other Eastern nations, had their roofs quite flat. The Greeks appear to have been the first who made their roofs with a slant each way, from the middle to the edges. This was very gentle, the height from the ridge to the level of the walls not exceeding one-eighth or one-ninth of the span, as may be seen by many ancient temples now remaining. In Northern climates subject to heavy rains and falls of snow, the ridge must be very considerably elevated. In most old buildings in Britain, the equilateral triangle seems to have been considered the standard both in private and public edifices, and this pitch continued for several centuries, till the disuse of what is called Gothic architecture. The ridge was then made somewhat lower, the rafters being *three-fourths* of the breadth of the building. This was called the *true*

pitch; but subsequently the half square seems to have been considered the true pitch.

The heights of roofs were gradually depressed from the half square to one-third of the width, and from that to a fourth, which is now a very general standard, though they have even been executed much lower.

There are some advantages in high-pitched roofs, as they discharge the rain with greater facility; the snow continues a much shorter time on the surface, and they are less liable to be stripped by heavy winds.

Low roofs require large slates, and the utmost care in their execution; but they have the advantage of being much cheaper, since they require timbers which are shorter and of less scantling. When executed with judgment, the roof is one of the principal ties to a building, as it binds the exterior walls to the interior and to the partitions, which act like strong counter-forts against them.

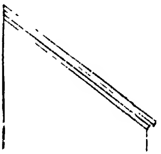


Fig. 88.

Roofs are of various forms, according to the nature of the plan, and the law of horizontal and vertical sections. The most simple form of a roof is that which has only one row of timbers arranged in an inclined plane, which throws the roof entirely on one side; this is called a "lean-to" or shed-roof (Fig. 88).

The most general roof for an oblong building consists of two rectangular planes of equal breadth, equally inclined, and terminating in a line parallel to the horizon. Consequently, its form is that of a triangular prism (as in the church, Fig. 86), each side being equally inclined to the plane of the wall-head; this is generally called a "pent-roof" (Fig. 89 is the end view, or "gable," and Fig. 90 is the plan of such a roof).

When the plan is a trapezium, and the wall-heads properly levelled, the roof cannot be executed in plane surfaces, so as to terminate in a level ridge. The sides, therefore, instead of being planes, are made to wind in order to have the summit parallel to the horizon; but the most eligible method is to make the sides of the roof planes, enclosing a level space or flat, in the form of a triangle or trapezium, at the summit of the roof.

Roofs flat on the top are said to be *truncated.* These are chiefly employed with the view to diminish the height, so as not to predominate over that of the walls.

When all four sides of the roof are formed by inclined planes, it is called a "hipped" roof (Figs. 91 and 92), in

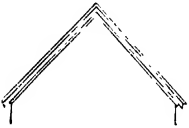


Fig. 89

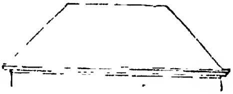


Fig 91

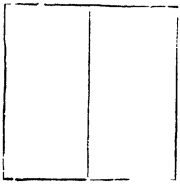


Fig. 90.

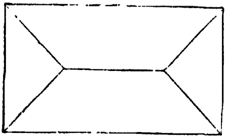


Fig 92.

Fig 93.

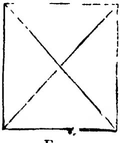


Fig 94.

which case two of the inclined sides—namely, those which slant from the long sides of the building—will be *trapezoids*, and the other two *triangles*.

But if the building to be covered be *square* (Figs. 93 and 94), and all the sides slant equally, the roof will form a square pyramid, for the projection and development of which, see "Projection," page 57.

A building having a hipped roof consists of a square

prism, on which a triangular prism rests, as in Fig. 82; but the ends of the prism are slanted off.

When the planes of roofs, instead of being continued until they meet in a ridge, take another slant at a certain height, they are called "curb" or "Mansard-roofs" (Fig. 95), from the name of their inventor, a great French architect who lived in the sixteenth century. They are much employed in France, and are hence often called French roofs. When the plan of the roof is a regular polygon, or a circle, or an ellipse, the horizontal sections being all similar to the base, and the vertical section a portion of any curve, convex on the outside, the roof is called a Dome.

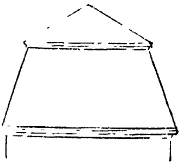


Fig 95.

The following terms are constantly used in relation to roofs, and the explanation of them here will be found of service, although some of them have already been given in "Building Construction."

Wall-plates are pieces of timber laid on the wall in order to distribute the pressure of the roof equally, and to bind the walls together. Were it not for wall-plates, the tie-beams of a roof or the joists of a floor would rest on single bricks, whilst the spaces between the joists would not in any way assist in bearing the load. The wall-plate lying on the whole length of the wall, therefore, spreads the pressure over all the bricks, and the trusses, or joists, rest on a frame of timber.

Trusses are strong assemblages of timber, generally of a triangular form, serving to support the purlins on which the common rafters rest. They are disposed at equal distances, and are used when the expansion of the walls is too great to admit of common rafters alone, which would be in danger of being bent or broken by the weight of the covering, for want of some intermediate support.

They are variously constructed, according to the width of the building, the contour of the roof, and the circumstances of the walling below.

Tie.—Any piece of timber connected at its extremities

to two others acted upon by opposite pressures, which have a tendency from each other, or to extend the tie as a rope or chain.

Straining-piece.—A piece of timber connected at its extremities to two others acted upon by opposite forces, which tend to press them together. The straining-piece, by being placed between them, serves to keep them apart, and, further, acts as an abutment for the external pressure.

Hence, a tie and a straining-piece act in a manner exactly opposite to each other—the one draws the ends of two pieces of timber *together*, the other keeps them *apart*. A rope, chain, or iron rod could be used for the tie, but the straining-piece, which has to bear end pressure, must always be stiff and inflexible.

Principal Rafters, or, as they are sometimes called, "principals," are the two pieces of timber which form the sides of a truss; their lower ends being mortised into the end of the tie-beam, or resting in an iron shoe, whilst their upper ends abut on and support the head of the king-post.

Purlins.—Horizontal pieces of timber resting upon the principal rafters, and at right angles to them; they pass from truss to truss, and across these again are laid the

Common Rafters, which are pieces of timber of a smaller section, placed at equal distances across the purlins, parallel to the principal rafters. They support the boarding or battens to which the slating is fixed.

The **Tie beam** is the horizontal piece of timber which forms the base of the triangle or other figure of which the truss may consist. As already mentioned, it receives the ends of the principal rafters, and is strapped up to the king or queen posts. The tie-beam answers a two-fold purpose—viz., that of preventing the walls from being pushed outwards by the weight of the covering, and of supporting the ceiling of the room below. In some cases it is found desirable not to place a tie-beam at the foot of the rafters, but to use it as a connecting link higher up, something like the horizontal line in the letter A; in this case it is called a **Collar-beam.**

King-post.—This is an upright piece of timber in the middle of the truss. Its upper end acts as a key-stone of

an arch, against which the principals abut, and, being thus supported, the tie-beam is strapped or bolted up to its lower end, and thus, not only is sagging, or sinking, prevented, but abutments are formed for struts, which give support to the principals in points between the tie-beam and the king-post.

Queen-posts.—Upright pieces of timber, framed above into the principals, and supported by a straining-piece or strut, whilst to their lower ends the tie-beam is bolted or banded up at points between the wall-plates and the king-post. Some trusses are constructed without king-posts: queen-posts only being used.

Struts are oblique straining-pieces, framed below into the king or queen posts, and above, into the principal rafters, which are supported by them; or sometimes they have their upper ends framed into beams which are too long to support themselves without bending. They are often called *braces*.

Puncheons are short transverse pieces of timber fixed between two others for supporting them equally. They are sometimes called *studs*.

Straining-beam.—A piece of timber placed between the queen-posts at the upper ends, in order to withstand the thrust of the principal rafters.

Straining-sill.—A piece of timber placed between the lower ends of two queen-posts, upon the tie-beam, in order to withstand the force of the braces, which are acted upon by the force of the covering.

Camber-beams.—These are horizontal pieces of timber, made sloping from the middle towards the ends on the upper edge. They are placed above the straining-beam in a truncated roof, for fixing the boarding on which the lead is laid. Their ends run three or four inches above the sloping plane of the common rafters, in order to form a roll for fixing the lead. This is shown in Fig. 96, which is the roof-truss of the chapel of the Royal Hospital at Greenwich, constructed by Mr. S. Wyatt.

Auxiliary Rafters are pieces of timber framed in the same vertical plane with the principal rafters, under and parallel to them, for giving additional support when the extent of the building requires their introduction. They are sometimes called *principal braces*, and sometimes "cushion rafters."

Joggles.—The joints at the meeting of struts with king-posts, queen-posts, or principal rafters, or at the meeting of the rafters with king and queen posts. *The best form is that which is at right angles to the length of the struts.*

Cocking, or Cogging.—The particular manner of fixing the tie-beams to the wall-plates. One method is by dovetailing, the other is by notching the under side of the tie-beam, and cutting the wall-plate in the reverse form to fit it.

Ridge-tree.—A piece of timber fixed in the vertex of a roof, where the common rafters meet on each side of it. The upper edge of it is higher than the rafters, for the purpose of fixing the lead which goes over it to cover the ends of the slates in the upper course.

Straps.—Thin pieces of iron running across the junction of two or more parts of a truss or frame of carpentry, branching out from the intersection in the direction of the several pieces. They ought always to be double—viz., one on each side of the timbers, and their ends strongly bolted to each of the pieces.

The uses of these various parts will be illustrated in the subsequent examples; but it must be understood that though every one of them *may* be found in the same roof, it is not necessary that any complete roof should have them all. The introduction of many of them depends on the distance of the walls, the contour of the roof, the partitions below, the quantity of head-room wanted in the garrets, &c.

It has already been stated that although the main intention of this book is to teach drawing, still it is not desired that it should be a drawing-book only, and, therefore, as much instruction as it is thought the student may require in the proper delineation is given, but the limits of the work preclude any lengthened treatise on the principles of construction. The student is therefore referred for the general subject of Roofs to "Building Construction," page 103, and Fig. 117, in which the position of most of the parts alluded to have been shown; and it is further intended to devote a separate volume to the elucidation of this important branch of building construction.

The three annexed illustrations, from three excellent English examples, are here given, as affording not only

sound instruction in the principles of construction, but as good studies for drawing.

Fig. 96 is the truss employed in the roof of the chapel of the Royal Hospital at Greenwich, already alluded to.

It is constructed with two queen posts, B B, and has two struts, C C, from the foot of the queen-posts to the straining-beam, D, and which abut against a second straining-piece, E, underneath the first. The tie-beam, A, is also further suspended from the straining-beam by an iron rod, H, which answers the purpose of a king-post.

The following are the scantlings of the various timbers, which are given to enable the student to work this example to a regular scale, and which should not be smaller than a quarter of an inch to the foot.

		Inches scantling.
A.	The tie-beam, 57 feet long, the span of the walls being 51 feet	14 × 12
B.	Queen-posts	9 × 12
C.	Braces	9 × 7
D.	Straining-beam	10 × 7
E.	Straining-piece	6 × 7
F.	Principal rafters	10 × 7
G.	Camber-beam for platform	9 × 7
H.	Iron rod supporting tie-beam	2 × 2

The trusses are seven feet clear apart. The platform is covered with lead, which is supported by horizontal beams 6 × 4 inches. The timbers of this are well disposed, and contain, perhaps, less wood than most roofs of the same dimensions.

Of course, the tie-beam must be drawn first, then the queen-posts, the principal rafters, and straining-beam; next, the struts and straining-piece; then follow the iron rod, the camber-beam, the purlins, and the covering.

Fig. 97 is the roof of St. Paul's, Covent Garden, London, designed by Mr. Hardwick and constructed by Mr. Wapshot in 1796.

This roof, although of the same general construction as the last, varies from it in several particulars.

There is a second pair of principals, H H, which are supported on the lower, F F, by studs, and the lower principals thus become only auxiliaries. The queen-posts, B B, are continued up to the principals, and a king-post, D, is carried from the apex to the straining-beam.

The following scantlings are given for the same reason as in the last case

		Inches scantling
A.	The tie-beam, spanning 50 feet 2 inches ...	16 × 12
B.	Queen-posts ...	9 × 8
C.	Straining-beam ...	10 × 8
D.	King-post (14 inches at the joggle) ...	9 × 8
E.	Struts ...	9 × 8
F.	Auxiliary rafters at bottom ...	10 × $8\frac{1}{2}$
H.	Principal rafters at bottom ...	10 × $8\frac{1}{2}$
I.	Studs supporting the principals ...	8 × 8

It will be seen that this roof consists of an outer truss supported by an under one, the whole projecting seven feet beyond the walls.

Fig. 98 represents the present roof of Drury Lane Theatre, London. Here are both principal and auxiliary rafters, the tie-beam being suspended at two points from the former, and two from the latter, the two first queen-posts being the inner ones. These are kept apart by the straining-beam, against which they are pressed from the outer side by the auxiliary rafters. Struts are placed between the feet of the principal and the heads of the secondary queen-posts, and the bearing of the sub-rafters is still further reduced by a strut from the foot, and on the other side of the smaller queen-posts. The straining-beam is supported by a king-post, from the apex of the principals, which in their turn are supported by struts from the foot of the king-post, the other portion having a continuous bearing on the auxiliary rafters.

Fig. 99 shows how the timbers are joined and strapped at the top of the queen-posts, the whole being tightened up by iron wedges at the lower end of the iron strap, as already described in relation to king-posts in "Building Construction."

Fig. 100 shows how the ends of the tie-beams are strengthened by saddle-pieces, and how the principal and auxiliary rafters are inserted and bolted on to them. It will be observed that the heads of both the bolts pass through the same iron plate, which is bent at the oblique part of the saddle-piece, so that the head of the bolt may be at right angles to its length.

The method of drawing both the last figures is so

precisely similar to the previous example, that no further instructions are deemed necessary.

Having the advantage of the co-operation of the heads of various Continental technical schools, I am enabled to introduce several examples used in those institutions, some of which are well worthy of our imitation, and from all of which most important instruction may be derived.

Fig. 101 is the transverse section of a German agricultural building, the lower part of which is used as a stable, or cattle-shed, and the upper floor as a loft for storage of hay, grain in the sheaf, &c.

It will be remembered that the great object to be constantly kept in view in designing a roof is that its weight must not press *outward*, but *downward*, and this object is best attained by carrying the bearing as low down as possible.

In this example the walls are doubly tied together; first, by means of the tie-beam, which rests on corbels fixed on the lower portion of the wall, which is thicker than the upper. The principal weight of the roof is carried down to this by means of the struts, *h h*, and to these the ties, *o*, are attached, whilst the cross-pieces act as hammer-beams, being attached at their one end to the struts, and at the other to the end of the principals. The principals cannot thus spread outward, and as the hammer-beams, *i*, rest on the wall-plate, *k*, on the upper edge of the wall, a second tie is secured. The principals are further confined at the top by a collar-beam, *l*, suspended from the king-post. The tie-beam is supported on bridging-joists, which run parallel to the *length* of the building, and are supported on posts, *d d*, the bearing of which is increased by the cross-pieces, *f*, shown in Fig. 102, which is a portion of a longitudinal section, in which will also be seen the method of giving additional support to the ridge-beam by the struts, *n n*.

The floor-joists are shown at *a a* and the purlins at *p* in both sections.

Fig. 103 shows the method in which the ridge-tree is attached to the head of the king-post, and Fig. 104 shows the joggle by which the ends of the principals are inserted.

Fig. 105 is a portion of a truss of a similar character drawn to a larger scale. As the trusses must necessarily

be several feet apart, the purlins, which are, of course, of a smaller scantling, would be liable to sag. In Fig. 106, therefore, is shown the method adopted for giving support to their ends. This method consists in the placing additional end-pieces. First, a longitudinal beam, *h*, is fixed at right angles to *g*, and, therefore, parallel to the wall-plate. The end-pieces are precisely similar in character to the end of *g*, and are inserted into *h* by means of a tusk-tenon wedged in. This is shown as a separate example in Fig. 107.

As to the mode of drawing this example, the walls should, of course, be drawn first, then perpendiculars for centre-lines for the supporting columns, then the corbels and tie-beam.

It will now be found convenient to draw the section of the wall-plates, the lower line of the principal rafters, the struts *h*, the hammer-beams, the king-post, collar-beam, floor-joists, and then to complete the columns and draw the purlins, &c.

The longitudinal section, Fig. 102, should be *projected* from Fig. 101 by drawing horizontal lines from the edges of the various members shown in Fig. 101.

Fig. 108 is the section of a roof in which, although the tie-beam rests on the top of the walls, still the weight is carried downward to a much lower point This is effected by means of perpendiculars, *a* (see enlarged view, Fig. 109), and struts, *c*, which being double, clasp the tie-beam, *b*, between them, as shown in the enlarged section, Fig. 110, and carry the weight, not only of the principals, *c*, but of the common rafters, *d* (to which it will be seen they are also attached), down to a stone corbel built into the wall; the king-post being also made double, clasps around both tie-beam and collar-beam, and the mutual support thus given admits of timber of smaller scantling, and consequently of less weight, being used.

Fig. 109 is an enlarged view of the end of this truss, and Fig. 110 is a cross-section projected from it, the members being similarly lettered will be self-explanatory.

Fig. 111 shows how the double wall-plates are connected by cross-pieces dovetailed into them. The sketch also shows the intermediate end-pieces, *f*, and the manner in which they are secured by the longitudinal beam, *g*.

Fig. 112 is the elevation of the end of a truss of a similar character, and Fig. 113 is the upper end of a strut clasped by a collar-beam inserted into a principal.

In another portion of this manual, the De Lorme system of building up arched ribs has been alluded to, and it will be remembered that this consists in uniting timbers placed on their edges; these timbers being in short lengths, each cut out of the flat so as to form a portion of the required curve, the different lengths being united by what is called the "break-joint."

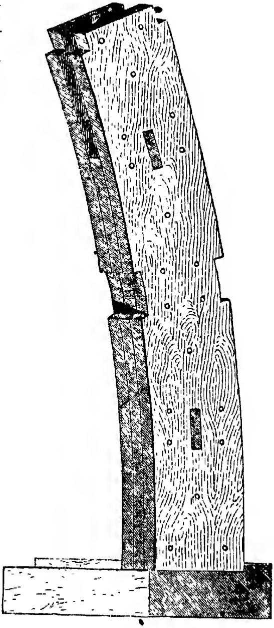


Fig. 114.

This system has been used more or less ever since its invention. The roof of the middle compartment of the building formerly known as the Pantheon, Oxford St., London, is constructed on this principle; but owing to the strength of the beams being so much dependent on the lateral cohesion of the fibre, the system has not been generally adopted in roofs, but has on the Continent been used in several large *domes*. The arch-beams of the original dome of the Halle au Blé, at Paris, built by Messrs. Legrand and Molino, was of this character, but this having been destroyed by fire, has been replaced by an iron one. The span of the original dome at its base was

120 feet. The largest dome in Germany constructed on the De Lorme principle is that of the Catholic Church at Darmstadt, a portion of one of the arch-beams of which is given in Fig. 114. These arched beams, however, do not continuously span the entire well—the diameter of which is thirty-three and a half metres—but abut at the top against a ring, which is the base of the lantern, or skylight.

The ribs are not all carried up the whole height, but are alternated by narrower ones, which reach about two-thirds of the length of the others, the main ribs being constructed of five thicknesses of timber at their lower half, and of three above the middle—the intermediate ribs consisting of three thicknesses only.

In fixing these ribs in their places, the plates were, in the first place, merely nailed together; they were afterwards permanently connected, and prevented from altering their shape by bands of timber (*b b*, Fig. 115) running all round at regular heights; and these are bolted together as shown at *c c*, Figs. 116 and 117. The plates being further prevented separating laterally by the cross-pieces, *d d*, Fig. 116. The ribs are further stayed by additional bands running all round through the middle of their width. The openings for these timbers are shown in Fig. 115, and all the parts will be seen in their proper places in Fig. 118, which is a view of a portion of a dome, showing the lower ends of the main ribs, A A, and of an intermediate rib, B. The external and internal bands, *b b*, will be seen notched on to the ribs and united by the bolts, *e e*, at the sides of which are also seen the wooden cross-pieces, *d d*, (Fig. 116); *c c* is the intermediate band, with wedges, *d d*, the purpose of which is to cramp the plates together laterally. The proper mode of projecting such views of domes will be given in a subsequent figure, it being desirable, at this stage, to contrast the De Lorme system with that of Emy. This system has already been described and illustrated (Figs. 64, 65, &c.) in a former section, and it will therefore be sufficient to show how it has been applied. The example (Fig. 119) chosen for this purpose is a portion of the roof-truss of the riding-school, at Libourne, near Bordeaux. The roof is not of the dome character, but covers a building of a rectangular form.

The arch-rib, built up five plates placed horizontally on each other, and joined as already shown in Fig. 64, abuts against perpendicular double-posts, A, resting on corbels,

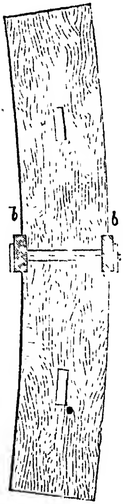


Fig. 115.

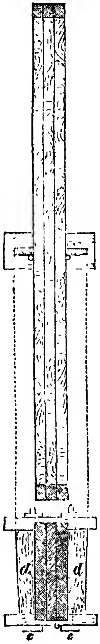


Fig. 116.

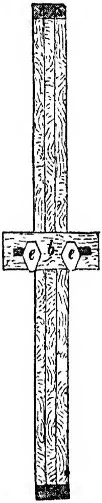


Fig. 117.

B, built into the wall, which is one-third wider below than it is above this point. At the top of this wall-post is a strong cross-piece, C, resting on the stone cornice, D, which covers the whole width of the top of the wall; and

This in its turn is laid on the wall-plate, which is placed on the *outer* face of the wall, so that it will be seen that the entire weight of the roof presses *downward*, or in the direction of the wall, and that the tendency of the whole truss must be to tie the walls together, not to force them outward; and this, as has already been explained in "Building Construction," is the leading point to be kept in view in designing a roof. The principals, E, abut upon the cross-pieces, C, and are tied to the perpendicular by the struts, F, and to each other at the top by the collar-beam, G. To the frame thus formed, braces, H I J, &c., are attached, *converging to the centre of the arch-truss* (these braces are double) and clasp the arch-truss, the principals, and the ties, F, between them - being themselves bound together by means of blocks and bolts, the ends of which are shown in the illustration. The arch-truss is confined at the foot of the wall-post by an iron band, tightened by a screw-bolt. This arrangement is shown in Figs. 120, the section; 121, the side elevation; 122, the front elevation.

In drawing this example, the student cannot do better than follow the construction as described, and draw the various members in the order in which they would be employed in the construction. He will, by this mode of proceeding, learn to *make* a drawing in an intelligent manner, instead of merely *copying* the lines. It is advisable that the drawing should be made of at least twice the size of the original, and if neatly inked and nicely coloured will become an important addition to the portfolio. This affords an opportunity of advising each student to provide himself with a portfolio, and to keep his drawings *flat*. When drawings are rolled one over another, they are put away in a drawer or cupboard (if indeed they are so taken care of); those which were drawn first are buried in the depths of the roll, are seldom seen, and are often entirely forgotten; even if taken out for reference, they will not keep flat, but are wrinkled and difficult to measure from. On the other hand, if the drawings are neatly cut off the board, and kept in a portfolio, they are constantly kept before the eye, and the student is thus reminded of subjects and of principles, which would otherwise have formed only a single study, possibly never to be looked at again. Portfolios may now be had at a

very low price, and the student is assured that the small amount will be very well laid out.

The following illustrations are examples of roofs in which iron is combined with wood - by which means far greater lightness is attained than when wood only is employed. The construction of such roofs will be more fully described in a subsequent volume devoted entirely to this section of the subject, and therefore the general purposes only of the various members will be spoken of in this place. Fig. 123-- A A and B B are tension-rods; by screwing up the nuts at the ends of these, the straining-pieces, D D, are forced upward, and being perpendicular to the principals, they give support to them at their middle points. When these tension-rods are tightened, it will be seen that the tie-rod, C C, is also strained, and perfect stiffness is thus attained.

Fig. 124 shows the manner in which the principals meet. The apex is covered by an iron plate; this is bent downward so as to form a base for the nuts, which shall be at right angles to the tension-rods. The nuts are double in order to cause them to act upon a greater length of the rod than would be the case if single ones were employed.

Fig. 125 illustrates the manner in which the nuts act at the lower ends of the principals, a cast-iron boss being attached to the wood-work, with one face slanting, so that in this case also the faces of the nuts may be at right angles to the tension-rods.

Fig. 126 is a roof-truss on precisely the same principle as the other—the difference being merely that the straining-pieces, A A, are of wood instead of cast iron; at their lower end, however, they are fitted with a wrought-iron shoe (Fig. 127, B B) into the ringed end of which the tension-rods hook. These hooks are confined by rings, and their ends are then bent round as shown at C C and A.

Fig. 128 is a section of a cast-iron double shoe, or housing, for the reception of the upper ends of the principals, and also for the support of the ridge-timber; a plate extends below the shoe for the attachment of the tension-rods.

Fig. 129 is a similar subject, with an extra breadth of plate, and a third hole into which the end of a vertical tension-rod, which acts as a king-post, is bolted,

Fig. 130 shows the cast-iron shoe for the reception of the lower ends of the principals.

Fig. 131 is a truss used in a railway-shed in Paris, designed by M. Armand. This is an application of Emys' system of building up the arch-beam of plates of timber,

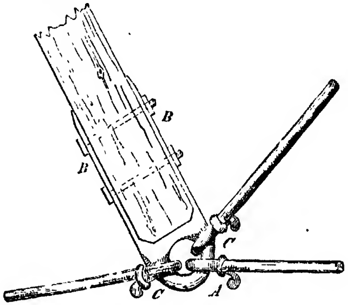


Fig. 127.

and to this is added a wrought-iron tie-rod, by which the ends are confined; this is tightened up by the tension-rod, A B, in the middle.

Figs. 132 and 133 are the elevation and plan of the junction at B, showing the means by which the tie-rod is tightened up. Fig. 134 shows another arrangement for attaching and tightening a tension-rod.

THE DEVELOPMENT OF THE SURFACES OF ROOFS.

Although the whole subject of the development of prisms has been treated of in "Projection," it is deemed desirable to give two examples here, showing the immediate application of the principles to roofs, in order to enable the student to find the exact shapes of the surfaces of which they are composed; and, as in the case of a hipped roof, the length of the hip-rafters.

Fig. 135. In this figure, *a*, *b*, *c*, *d* is the plan of the building to be covered by a hipped roof.

To draw the plan of the roof, bisect the angles of the

parallelogram, and the bisectors meeting in *e* and *f* will form the plans of the hip-lines, and the line joining *e* and *f* will be the plan of the ridge.

It is now required to project the elevation from this plan. To do this, draw any horizontal, as A B (Fig. 136), and the perpendiculars, from *c*, *e*, *f*, *d*, cutting A B in *g*, *h*, *i*, *j*, and produce *h* and *i* indefinitely.

Produce the perpendicular at *e* until it reaches *l*; then it will be clear that *k l* is the width of the roof-trusses (at *k l* and *m n*), which would be at right angles to the sides *a b* and *c d*.

Draw *k' l'*, Fig. 137, equal to *k l* in Fig. 135, and at the middle point, *o*, draw the perpendicular, *o p*, equal to the *real* height of the truss; which is, of course, a matter dependent on the design of the architect. This triangle, then, will be the shape of the truss at this point, and is the section *across* the roof.

Make *h q* and *i r* in Fig. 136 equal to *o p* in Fig. 137; draw *g q*, *q r*, and *r j*, which will complete the elevation; and this will also be the longitudinal section through the ridge.

We now have to find the real length of the hip: to do this, draw *f s* (Fig. 135) equal to *o p* (137), and at right angles to *f d*; join *d s*, then the right-angled triangle, *d f s*, is the true shape of the hip-truss. This will be understood by cutting a piece of cardboard of this shape, and placing it on its edge on *d f*, then it will be seen that *d s* will be the length of the hip.

To develop the covering of this roof. It will, of course, be understood that this will consist of four planes, which will meet at the hip-lines. Now, it has already been shown that the ends are triangles, of which *a e c* and *b f d* are the plans, the length of lines *a c* and *b d* remains unaltered, but the *real* length of *c e*, *a e*, *b f*, and *d f* has been proved to be *d s*; therefore on *d b* and *a c* construct isoceles triangles, having *d s* for the two remaining sides; these triangles then, *a t c* and *b u d* are the true shape of the coverings of the ends of the roof.

Now from *c* and *d*, with radius *c t*, describe arcs cutting the perpendiculars *k* and *m* in *v* and *w*; join *d w*, *v c*, and *w v*; then the trapezoid, *c v w d*, is the development of one of the planes forming the side of the roof-covering. The same length set off on the perpendiculars

$l\ n$, will give the points $x\ y$, which will complete the fourth plane.

We will now proceed to find the form of the hip when the roof is a groined one.

Let me ask you to imagine yourself standing on the platform of a railway at the side of a semicircular arch by which a road is carried over it; you will then see that whilst the face or elevation of the arch where it crosses the railway at right angles is semicircular, its span being of course the diameter of the circle of which it is the half, the length from the springing near which you are standing, to the most distant springing (that is, the one on the opposite side of the line at the other end of the arch) will be much longer; yet the arch there is *not any higher*, although its span thus taken crosswise is longer, because the diagonal of a square or other rectangle is longer than its sides. The principle on which to find the shape of the curve which would reach from the springing at which you are standing to the one referred to, is also shown in Fig. 138.

On $a\ b$ describe a semicircle, and from the points 1, 2, 3, 4 erect perpendiculars cutting the semicircle in 1′, 2′, 3′, 4′ (or mark off *any* divisions in the semicircle, and from them draw perpendiculars to $a\ b$). Now, from the points where the lines 1′, 2′, 3′, 4′, &c., cut $a\ c$, draw lines perpendicular to $a\ c$, make each of these equal in height to those correspondingly lettered in the semicircle, and the curve drawn through their extremities will be the form required.

This study has already been fully worked out at Fig. 75 in "Building Construction," to which the student is referred; it is, however, necessary to the continuity of the present branch of our subject that we should in this place repeat Fig. 78 and its elucidation, as the lesson therein given forms a step in the present course.

Fig. 139 Here A B C D is the plan of a building to be covered by a groined roof.

The arch, the springing of which is A C and B D, is a semi-cylinder.

The arch which has its springing in A B and C D, being of the *same height* but of wider span, is a semi-*cylindroid.*

A cylindroid is a solid body of the character of a cylin-

der. But whilst in a cylinder all sections taken at right angles to the axis are circles, in the cylindroid all such sections are *ellipses*. It is, in fact, a flattened cylinder.

The curve at the groin, then, is generated by the penetration of a cylindroid and cylinder.

On A B describe the semicircle which represents the form of the arch at the ends A B and C D, and divide it into any number of equal parts, *a b c*, &c. It is only necessary to use the quadrant, as throughout the working the measurements are the same on each side.

Draw the diagonals A D and B C.

From *a b c d e f* draw lines perpendicular to A B, and cutting the diagonal A D in *a' b' c' d' e' f'*, and set off the same distances on the other half of the diagonal.

From these points draw lines at right angles to A C, and passing through it in points 1 2 3 4 5 6 7 8 9 10 11, mark off on the perpendicular 6 the height 6 *f* equal to the height of the semicircle *f*, and on the perpendiculars 5 4 3 2 1 mark off in succession the heights of the perpendiculars *e d f c b a*, as contained between the semicircle and the *diameter*. Set off the same heights on the corresponding perpendiculars on the other side of 6 *f*, and the curve traced through these points will be a semi-ellipse, which is the section of the semi-cylindroid forming the arch of which A B and C D are the springings.

We now proceed to find the curve of the groin; and it will be evident that, although the span is still further increased in length, the heights of the different points in the curve will be the same as in both the previous elevations.

The span, then, of the arch at the groin is the diagonal A D (or B C), to which the divisions *a' b' c' d' e' f'* have already been transferred from the semicircle, and from these the lines were carried at right angles to A C, on which the heights of the points in the curve were set off.

These points on the diagonal, then, will be seen to be common to both arches, since they are the plans of the points in the roof where the cylindrical and cylindroidal bodies penetrate each other. At these points, therefore, draw lines perpendicular to the *diagonal*, and mark off on these the heights of the perpendiculars in the semicircle from which the points on which they stand were deducted. These extremities being connected, the curve so traced is

the groin curve, and will give the shape for the centring for the groin, as the semicircle and semi-ellipse will for those used in the elevations of the arches.

It now only remains to develop the soffits or under surfaces.

Fig. 140. Draw any straight line, and commencing at A set off on it the distances into which the curve A C is divided (measuring on the *curve*, *not* on the springing-line), namely, the distances A a b c, &c.

At the points on the straight line thus marked, draw perpendiculars; make the middle one equal to 6 f, those on e e equal to 5 e, those on d d equal to 4 d, those on c c equal to 3 c, those on b b to 2 b, and those on a a equal to 1 a. Join the extremities of these perpendiculars, and the two curves meeting in a point, and joined by the original straight line, will form the development of the soffit of the cylindroidal arch.

Fig. 141 is the development of the semi-cylindrical arch. As this is worked in precisely the same manner from the *semicircle*, no further instructions are deemed necessary.

Fig. 142 is the plan of a building to be covered by a roof of a pyramidical form, the hips, however, being *curved* instead of straight, so that the roof is really a square dome.

Now in this case, the given rib crossing from B to B, and that which would cross it at right angles through the centre, is shown at B, which is the form of wooden centring which would be used to divide the semicircle into any number of equal parts. Draw diagonals in the square, and from the divisions in the semicircle draw lines perpendicular to the diameter, and cutting the diagonal; at these points erect perpendiculars, and make them equal to those in the semicircle; then the curve drawn through their extremities will be the shape of the hip. This is shown lying down in the illustration, and the student is advised to cut the form in cardboard, when by standing it on its edge against a semicircle placed on the line B B, he will be able thoroughly to comprehend the difference between the forms caused by their positions.

When a roof is constructed as in this figure, but the curve is truncated, or cut short by a flat surface, it is called "coved and flat."

Ceilings are sometimes built in this manner. They

form a sort of compromise between a flat ceiling and the various arched forms practised by the ancients. They do not require so much height as the latter mode, and have therefore been of considerable use in the finishing of modern apartments; but although the form is admired by many, it naturally is wanting in the elegance and grandeur of entire arched ceilings, nor does it admit of that beauty of decoration of which they are susceptible.

DRAWING FOR JOINERS.

The limits of this volume now render it necessary that some attention should be paid to such studies as form examples for drawing for joiners. Yet I would not wish to be understood that the lessons hitherto given do not appertain to joiners, or that those about to be given possess no value to carpenters. It is difficult to say what is the exact boundary which divides the two branches of wood-work. The general rule, however, is that carpenters' work is structural, and connected with the carcase, whilst that of a joiner comprehends the finishings of the outside and inside of a building. Of course, greater refinement and nicety is required by the joiner in practice; but this will not hurt the carpenter, nor can the structural knowledge required by the carpenter fail to benefit the joiner. In fact, a general knowledge of the practice of each will make both work with greater economy, for one will work into the other's hands; their work will, to use a technical term, "dovetail" together, therefore the two branches are not separated here by a hard line; and that the student may see that the higher branches of joinery approach cabinet-making and wood-carving, examples belonging to both of these branches are introduced. We all know the pleasure it is to meet with a joiner who, in addition to the work of laying down floors, putting up wainscots, or fixing window-sashes, can, when required, set out and execute a piece of Gothic panelling or an organ screen, or who can carve any portion of the turn of a moulding which cannot be worked with the plane or struck by the machine.

Although, therefore, in the volume on Building Construction, several methods of uniting timber have been given, a number of examples are added here, some of which, it will be seen, are used by carpenters and some by joiners.

Fig. 143 in the annexed plate shows a mode of lengthen-

ing timber, first by means of *halving*, and additionally by a *dovetail*. This joint is supposed to be supported from below, as in the case of a wall-plate, &c. The dovetail gives this joint power to resist any tension which might tend to pull the parts asunder, and also strengthens it against lateral pressure.

Figs. 144 and 145 are two forms of scarfing which are very generally used. The principles of scarfing having been fully explained in "Building Construction," it is not necessary to repeat them here. Fig. 145 shows the "sally," or point given to the end of each part to resist lateral pressure.

Fig. 146 is a joint effected by a tongue or tenon in the one part (*b*) fitting into a mortise or slit of similar width in the other (*a*). This is considered a very good joint when the beam so joined is supported by a column underneath the joint. In such case it may be placed on its narrow side, so that the width of the tongue may be vertical. The sides of the part *a* then strengthen the beam against lateral strain. This method, too, is found very effective when used vertically, there being no possibility of the parts slipping over each other. In this case the sally at the end must be formed by a very obtuse angle, and the edge of the points, and of the parts which receive them, must be worked very true, or there will be a chance of the wood being split by vertical pressure.

Figs. 147 and 148 are joints used for lengthening timber when supported by columns or walls.

Fig. 149 shows the common method of crossing two timbers at right angles, by means of halving, so that they may be flush. Of course, the joint is only half as strong as the timbers originally were, owing to half the thickness of each being taken out. If, therefore, they are of any considerable length, the joint must be supported.

Fig. 150 shows a joint of a similar character, but more complex in its working. It is not adapted for large works, being still more weakened by the cutting away of the pieces at the side.

Fig. 151 shows the method of halving when the timbers cross each other at any angle, and Fig. 152 is a separate view of one of the parts.

Fig. 153 exhibits two methods (*a* and *b*) in which timbers can be united at right angles to each other (*c*) when they

are not to cross. These illustrations are too plain to need any explanation.

Fig. 154 is one of the numerous methods for uniting timbers at an angle of a building by means of a dovetail joint, by which means the end of each is locked into the end of the other.

Fig. 155 shows another method by which one timber is notched on to another. This is a very good system, for the upper holds as it were by a hook, which acts against a shoulder in the lower. The upper is thus prevented being drawn inward by weight placed upon it, and the lower is strengthened against any pressure which might tend to force it outward.

Fig 156 is a joint of a similar character, a dovetail being employed in this case, which in Fig. 157 is further secured by an additional shoulder.

Figs. 158 and 159 are methods by which the ends of timbers are firmly attached to beams or wall-plates on which they rest. The upper surfaces are shown as cut for the reception of an upper timber to further bind them together.

Fig. 160 is the continental mode of constructing framed flooring, and is here introduced in order to compare it with our system, which has been explained and illustrated in "Building Construction." Here A is the girder, B B the bridging-joists, C the floor-joists. Here it will be seen that the ceiling-joist, D, is not notched on to the under surface of the binders, but is inserted by a tenon and groove. The groove or slot being made longer than required, the ceiling-joist is placed slantingly across between two binders, its ends being in the opposite ends of the grooves ; and by being struck with the mallet it is forced into its proper direction at right angles to the binding-joists.

Figs. 161 and 162 show four different kinds of oblique mortises. The principles on which such joints are worked have been given in "Building Construction" in connection with figures.

Fig. 163 shows the method of uniting boards, *a b*, in a flat surface, called *Dowelling*. The edges to be joined having been very accurately planed, holes are bored, pins as at *c* are glued into the one, and the projecting ends being inserted into corresponding holes in the edge of the other board,

unites them firmly—the edge of the board *c* and the end of the pin being glued.

Square pieces of hard wood, or dowels, are often used in the place of pins, and are shown at *d*.

Fig. 164 is a method frequently adopted in floor-boards and panelling. It is called *Rebating*, and consists in planing away half the thickness of the edge, so as to leave a ledge standing; all the boards being thus rebated, the ledge left on the one fills up the rebate, or "abated" edge of the other. This will be clearly understood on referring to the illustration.

Fig. 165 is the method of joining boards called "ploughed and tongued." In this case a groove is planed in the one edge, and a tongue left (by planing away the angles) at the other end of each board; the tongue of the one then fits into the groove of the other. In very good work it is usual to plough *both* edges, and *insert* a separate tongue. This tongue is formed of strips cut the cross way of the wood, as shown in Fig. 166.

Fig. 167. This method consists in working grooves across the back of the pieces, *a*, and forcing rabbets into them, as *b b*. The bottom of this groove is flat (A), and its sides slant inwards towards the bottom. The sides of the rabbet are also cut slantingly, and a joint is thus formed called the "dovetail notch."

This method is exceedingly well adapted for making drawing-boards. The rabbets must not then be glued, or otherwise fastened in, and thus by means of their dovetailed edges, they keep the board from warping, whilst at the same time they allow of its expansion and contraction, and thus splitting and twisting are prevented.

Fig. 168 is an illustration of the method of clamping the ends of boards, *a b*, by tonguing the board and ploughing the piece which is to cross it, *c*. Sometimes, instead of bringing the end of the cross-piece flush with the edge of the board, it is cut off at an angle, the board being cut correspondingly to admit of the insertion. This last method is called *mitre clamping*.

Fig. 169 shows a very common method of joining up a flat surface by means of framing and panelling. A groove is run in the edge of the frame, the edges of the panel are rebated, and the whole brought up flush.

Fig. 170 shows a portion of a panel inserted into a frame where a flush surface is not required.

Fig. 171 represents one of the many methods employed for angle joints. It is the simple mortise and tenon, a shoulder being left on the outer side of the tenon by which the one piece is secured against being forced out of perpendicular.

Fig. 172 is another method, which is accomplished by means of a mitre, part of the wood being left as a tenon at the end of the one part, which is inserted into the mortise at the end of the other. A pin is then passed through the whole.

DOVETAILING

Is of three kinds—common, lap, and mitre. *Common* dovetailing shows the form of the pins or projecting parts, as well as the excavations made to receive them. Fig. 173 shows the ends of the two boards *a* and *b* to be thus joined, and Fig. 174 shows the joint completed. Fig. 175 represents a variation of this form, used in attaching the fronts of drawers to the sides, and for similar purposes. Here the dovetail is shown on the one side only, a ledge being left at the end of *a* so that the ends of the dovetails of the side *b* do not penetrate quite to the front.

Lap dovetailing is similar to this, but in that system the ends of the dovetails of the side *a* are shortened, and the recesses which are to receive them in *b* are not cut through; when joined together, therefore, only the ledge is visible on the return side.

Mitre dovetailing--sometimes called also secret dovetailing—conceals the dovetails, and shows only the mitre at the edges. The manner in which this joint is effected will be understood from Fig. 176, in which the two parts A and B are given, each part being lettered to correspond with the position it is to occupy when the sides are joined. Concealed dovetailing is particularly useful where the faces of the boards are intended to form a salient angle, that is, one which is on the *outside* of any piece of work; but where the faces form a re-entrant angle, that is, a joint to be seen from the *inside*, common dovetailing will answer best; for, first, it is stronger, because the dovetails pass entirely instead of only partly through; secondly, it is cheaper, for the dovetails which go through the whole

wood take up so much less time in working than where a mitre has to be left; and further, if well executed, the dovetails are, by the very nature of the work, concealed internally.

Fig. 177 exhibits a method of joining two boards at right angles to each other. This is the simple mortise and tenon, and will not require any explanation.

MOULDINGS.

Mouldings are classed as Roman, Grecian, and Gothic. The Roman mouldings are all formed of parts of circles, and can therefore be struck with compasses. The Grecian are principally composed of parts of curves known as the conic sections—such as the ellipse or hyperbola. They are otherwise nearly similar to the Roman, which are therefore illustrated in this place as being the simpler and the more generally used. The modes of describing the conic sections will be found in "Linear Drawing," pages 68 to 80.

Fig. 178.—The moulding of which this is a section is called the **Ovolo**, or quarter-round. The fillet, or straight edge projecting beyond the curved portion, is to be drawn first, and then the horizontal, which represents the depth or bottom line of the moulding. Now produce the bottom line of the fillet, and on it, from the point at which the curve is to start, mark off the width of the moulding. This point, marked ⊙ in the cut, is the centre from which the quadrant is to be struck.

Fig. 179 is called the **Torus**, or half-round. Having drawn the fillet, and the line representing the bottom of the moulding, draw a line at right angles to these. Bisect the width of the curved part, and the bisecting point will be the centre.

Fig. 180 is the **Cavetto**, or hollow. This is a quarter-round, the curve turning *inward*. It is thus precisely the reverse of the ovolo.

Fig. 181 is a section of the moulding called the **Cyma Recta.** The exact form of this moulding is to a certain extent a matter of taste, since the curve may be made more or less full, as shown in the three examples Figs. 181, 182, and 183. To describe Fig. 181, draw a perpendicular across the depth of the moulding, and bisect it. From the bisecting point, as a centre point describe a quadrant;

through the centre draw a horizontal line, and from the point where the quadrant already drawn touches this line mark off the radius; then from this point as a centre describe the second quadrant, which will complete the form. In this and the subsequent curves composed of combined arcs the greatest care is necessary, so that the one may glide smoothly into the other without showing any break or thickening at the joining. To describe the Cyma Recta shown in Fig. 182, which is the form most generally used, let *n* and *o* be the points to be united by the moulding. Draw the line *n o*, and bisect it; with half *n o* as a base describe an equilateral triangle on the opposite sides of the line; then the apices* of the triangles will be the centres from which the curves are to be struck.

To describe Fig. 183, or others the curves of which are required to be more flat than in the last figure, draw the line *n o* as before, and bisect it. Bisect these two divisions again, and the centres will be on these bisecting lines, according to the form required; for, of course, the longer the radius the flatter the curve will be.

If it is required that the curve should be more full at the lower than at the upper part, it may be effected in the following manner, which is shown in Fig. 184:—Having drawn *n o*, divide it into *three* equal parts; construct an equilateral triangle, the base of which is two of these thirds, and on the opposite side of the line another, the base of which is the remaining third. The apices of these triangles will be the centres for the curves.

Fig. 185 is the **Cyma Reversa.** In this moulding the curve bulges outward at its upper part, its fulness being regulated by the taste of the designer. Thus it may be formed of two quadrants, as in Fig. 185; or of two semicircles, as in Fig. 186; or it may consist of the two arcs drawn from the apices of triangles, as in the cyma recta already shown.

Fig. 187 is the **Scotia.** This is a hollow moulding, sometimes consisting of a semicircle only—viz., the reverse of the torus. In other instances, as in Fig. 187, it is composed of two quadrants; and in others it is drawn from three centres, as in Fig. 188. To draw this, divide

* *Apices*—plural of apex. The upper point of a triangle.

the depth of the moulding into three equal parts, and with one third describe the quadrant *r u*; produce the horizontal *r u*, and from *r* set off *i*, equal to half *u r*. At *u* erect a perpendicular, and mark on it *u k*, equal to *i u*; draw *i k*, and bisect it; produce the bisecting line until it cuts *u k* in *s*. Draw *s i*, and produce it. From *i*, with radius *i u*, draw the next portion of the curve, meeting *s i* produced; then complete the curve by an arc drawn from *s* with radius *s u*.

A fillet (from the French word *filet*, a band) is the small flat edging used to separate two larger mouldings, to strengthen their edges, or to form a cap or crowning to a moulding. The fillet is one of the smallest members used in cornices, architraves, bases, and pedestals. When placed against the flat surface of a pedestal, it is usually joined to it by a small quarter-round hollow called the **Apophyge** (Fig. 189).

The torus, when worked very small, is called the **Astragal** (Fig. 190); but when worked so as not to project, as on the edge of boards to be joined, it is called a *bead*.

Figs. 191 to 198 are sections of **Gothic** mouldings. The whole of the construction lines are given in the illustration, and it is hoped the student will be able to work from these without any further aid. The whole subject of "Gothic Architecture" will be fully treated of in a separate volume of this series.

STAIRCASES.

The construction of staircases is considered the highest branch of joinery, and the drawing connected with them requires much attention.

Staircases may be divided into—(1) Geometrical, or such as are supported by or against a wall; (2) Bracket stairs, or such as are built in an opening or well, with strings and newels, and are supported by landings and carriages, the brackets mitring to the end of each riser; (3) Dog-legged stairs, which have no well-hole, the hand-rail of the progressive and the retrogressive flights falling in the same vertical plane.

The steps are fixed to strings, newels, and carriages; and the ends of the steps of the inferior kinds terminate only in the side of the string, without any housing.

Fig. 199 is the plan and Fig. 200 is the sectional elevation of a dog-legged staircase, with two-quarter winders that is, the two spaces at A and B, instead of being used as a landing, are divided into winding steps. In the plan *a* is the seat of the lower newel, and *g* is the seat of the upper newel. The dotted lines represent the faces of the risers—that is, the upright portion of the steps; and the full lines are the plans of the surfaces of the steps,

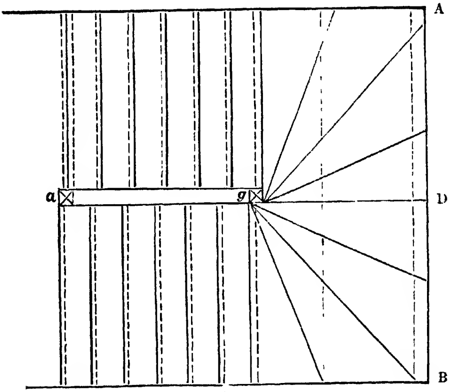


Fig. 199.

called the "tread." The edges of the steps are termed the "nosings."

In the elevation, A is the lower and B the upper newel. The upper part of each is generally turned, but is here, for simplicity, rendered necessary by the small size of the illustration, drawn as if square. C and D are the lower and upper string-board, framed into the newel.

In the setting out of staircases a *story-rod* is used. This is a very necessary article, and consists of a rod or rule, of the gross height of the complete story, or from the upper

surface of the boards of the one floor to the under surface of those of the other. It is divided into as many equal parts as there are to be risers, and from these the heights of the steps are to be gauged. In the construction of dog-legged staircases, the first thing is to take the dimensions of the stair and the height of the story, and to lay down a plan and section, representing all the newels and steps,

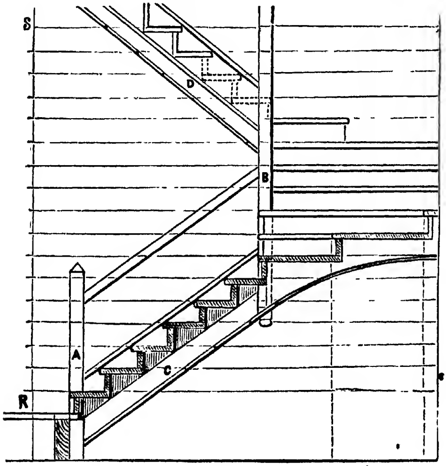


Fig. 200.

upon a floor, to the full size, or certainly to as large a scale as possible. Then the situations of the carriages, pitching-pieces, long-bearers, and cross-bearers will be ascertained, as also the string-boards; and the quantity of room required by the stairs at nine inches tread and six inches rise, as the case may be, will determine whether there are to be quarter-paces, half-paces, one-quarter winders, or two-quarter winders.

In drawing this example, or others of a similar charac-

ter, having drawn the rectangle, which is the plan of the well in which the staircase is to be built, divide it longitudinally into two equal parts: on each side of the dividing line set off half the width of newels and hand-rail. This will leave the space on each side which is to be occupied by the stairs.

Draw lines *g* 1, 2, 3, 4, 5, 6, 7; produce line 7 across the width of the baluster, and produce the line of the baluster until it reaches D; the newel will then occupy the right angle formed at *g*. Complete the plan of the newel, and produce the line of its face to E.

It will be seen that E A is equal to the length of the stairs, and that this is the case with D B; but that A 1 and B 7 are increased beyond a square by the addition of the thickness of the newel *g*. This will be clearly understood on referring to the drawing.

Now divide this rectangle into the number of equal parts required for the winders, and draw the edges of these radiating from the angles of the newel. From E set off the upper flight of stairs, and thus complete the plan.

In commencing the elevation draw a ground-line, and project the line of the wall from A B in the plan. Draw the story-rod, S R, and set off on it the heights required by the steps, and draw horizontals from each of these points; intersect these by perpendiculars drawn from 1, 2, 3, 4, 5, 6, 7 in the plan, and the points obtained by the intersections of these two sets of lines will give the edges of the stairs in the elevation. It will be seen that the points for the winders are obtained by drawing perpendiculars from the points where the edges of the winders in the plan cut the wall.

Next project the lower and upper newels, A and B, from *a* and *g* in the plan, and it will be seen that the lines of the handrail and string-board are parallel with a line drawn touching the edges of the stairs. Having drawn these, the arc forming the underneath line of the winders will complete the figure.

Fig. 201 is the plan and Fig. 202 is a section on the line A B of a staircase, with landing at half the height of the flight, and a narrow well between the ends of the stairs. The landing rests on three joists, *a*, *a*, *a*, which are stiffened by the cross-pieces, *b*, *b*.

The balusters and handrails are omitted in the section in order that the drawing may be rendered as simple as possible.

This study is to be worked on the same system as the last, the section being projected from the plan. It will be seen from the plan that the string-board turns at the end in the form of a semicircle; but although it turns *round* a semicircle, it must be remembered that it is at the same time *rising* to the next flight, and the curve it thus forms in the sectional elevation is a portion of a helix. In a drawing of the size of the example this curve might be drawn by the eye, but the power of doing this must be acquired by studying the true construction of the curve on a larger scale; for this purpose it is desirable to repeat in part the lesson given in "Projection."

The Helix.—If a piece of paper of the form of a right-angled triangle, A B C, Fig. 203, be rolled round a cylinder, *c*, the hypothenuse, or long side, A C, of the triangle, will generate a curve winding round the cylinder like a corkscrew.

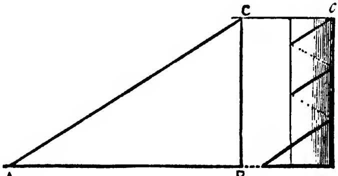


Fig 203.

This is called the helix, and it is this curve which forms the thread of a screw, and is the guiding line on which winding staircases are constructed.

To describe a Helix.—Let the circle A G in Fig. 204 be the plan of the cylinder around which the line is winding. Let the dotted perpendiculars A′ and G represent the elevation, and let the distance A to A 1 be the height which the curve has reached when it has travelled once round the cylinder, so as to be exactly over the spot from which it started.

This is called one revolution, and is the "pitch," that is, the distance from thread to thread in a screw.

Divide the plan into any number of equal parts, as A, B, C, D, &c., and divide A′ A 1 into the same number—namely, *a*, *b*, *c*, *d*, &c. Draw horizontals from *a*, *b*, *c*, *d*, &c.

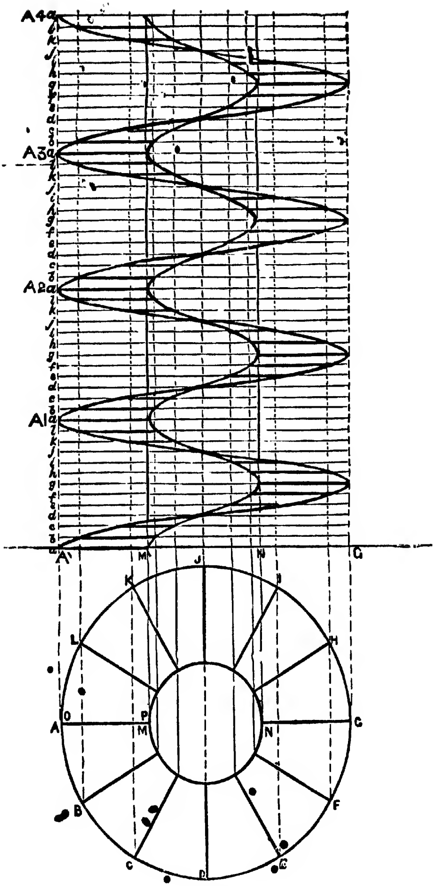


Fig. 204.

and perpendiculars from the corresponding points of the plan ; then the intersections of B with *b*, and C with *c*, will give some of the required points.

Now it will be seen that the points H, I, J, K, L in the plan are immediately at the back of B, C, D, E, and F, and therefore the same perpendiculars will pass through them, and thus the intersections of these lines with the horizontals correspondingly lettered will give the remaining points required for the formation of the curve.

Through all the points now obtained the curve may be traced by hand. To continue the helix, repeat the height of the pitch, as A 2, A 3, A 4 : divide these spaces as before, and from the points draw horizontals to intersect the *perpendiculars* already drawn ; for it will be evident that the corresponding points in each revolution will be immediately over each other.

Now let us suppose that, instead of a mere line being drawn round a cylinder, an *inclined plane* were to surround the smaller cylinder, M N.

You will understand this, perhaps, better if you cut out of paper the plan, A G. Cut the smaller circle, M N, away altogether, and cut through the line A M.

Place in the hole M N a cylindrical piece of wood of the exact size ; keep the edge A M fixed, but raise the edge O P. Then a rising plane or walk would be formed once round the small cylinder, and if this were constructed on a large scale, a person having travelled along this plane would have reached A 1, and be immediately over the point from which he ascended.

Now, a staircase is an inclined plane on which ledges or steps are placed to render the ascent easier, and it will be seen that if steps were placed on the inclined plane which winds around the cylinder M N, the principle of a circular staircase would be developed. The points for the inner curve are obtained by perpendiculars taken from the inner ends of the radii cutting the corresponding perpendiculars.

We now return to the winding portion of the string-board, the subject of the digression having been to show that although the few lines by which this is represented in the former example could be sketched by hand, it is only a knowledge of principles which can enable the student to draw with correctness and facility ; and further, that the principles involved in the proper delineation of

the curve in this example are those on which the projection of winding staircases, handrails, &c., is based.

Fig. 205 represents the plan and elevation of the portion of the string-board under consideration, projected on a plane parallel to the steps in the example, Fig. 202.

Having drawn the outer semicircle, *a b*, and the inner semicircle, *a' b'*, divide either into any number of equal parts, and draw radii; divide the height which the curve is to ascend into the same number of equal parts, and draw horizontals.

Draw perpendiculars from the extremities of the radii, and their intersection with the horizontals will give the points through which the helices representing the winding round a semicircular space will be developed.

Fig. 206 is the plan and Fig. 207 is the elevation of a winding staircase with solid central newel. In the plan, the dotted lines represent the plans of the risers, and from these, therefore, the perpendicular edges of the stairs must be projected; whilst the nosings of the steps are to be projected from the full lines in the plan. The student who has worked the previous figures, will not, it is presumed, require any further instructions in drawing this subject.

PARQUET WORK

Parquetry is a beautiful species of flooring; consisting of various patterns formed of different woods—such as cherry, oak, ebony, walnut, mahogany, maple, &c. It is very much used both in Germany and France, and is now becoming fashionable in England. The wood of which the parquetry consists is usually one inch thick, grooved, tongued, and keyed at the back and corners. It is well adapted for reception rooms and picture galleries, for borders round Turkey carpets, as well as for landings and panelling of rooms.

Fig. 208 is a very simple pattern for this kind of work, and is based upon the square and octagon. To draw this pattern, divide the width into three equal parts, and draw lines, dividing the length into three equal strips; across these again draw lines dividing the whole into equal squares. In one of these, as A B, draw diagonals; and from the angles, with a radius extending from the angle to the centre (C), describe arcs, cutting the sides of the square in D E, F G, H I, J K. Join E H, I K, J G, and F D, and an octagon will be inscribed in the square, as

per "Linear Drawing," Fig. 65. Measure the distance from the angle of the square to I or K, and set off the length of each of the four lines meeting at the angles of all the squares; join these points, and the design will be completed, and may be coloured according to taste.

Fig. 209 is a pattern of a similar character; the squares, however, bearing a smaller proportion to the side of the octagon than in the last example.

Figs. 210, 211, 212, and 213 are designs based upon the square only, and are too simple to require any instructions as to drawing, further than the advice already so frequently given: to work with the utmost accuracy, for in such repeating patterns, any one of the component figures being inaccurately formed, throws out the whole design.

Fig. 214. This design is drawn by setting out a number of squares. Draw diagonals and circles from the angles. All the other lines employed will be found to be parallel to these.

Fig. 215 is also based on the square Having set out a number of squares, divide the sides of each into three equal parts, and draw lines across so as to divide each of the squares into nine smaller ones. In each of the four small squares occupying the corners of the larger ones, draw one diagonal; and in each of the four squares occupying the middle of the sides, draw two diagonals. By shading the portions as in the example, the design will be developed.

Fig. 216 is based upon the hexagon. To draw this pattern, construct a line of regular hexagons, each touching two others by their angles; divide each hexagon into six equilateral triangles by diagonals. Find the middle of the sides, and draw lines to the middle points of the alternate sides; these will give two equilateral triangles crossing each other; and the required portions being coloured, the star in the centre will be left. The darker lines are drawn parallel to the sides of the hexagon.

FREEHAND DRAWING FOR JOINERS

(continued).

It is now deemed advisable to change for a while the course of studies, in order to give some little further attention to freehand drawing, and in Fig. 217 a Greek border,

composed of a leaf and dart, is presented—of course, with the understanding that it is to be copied on a very much larger scale; and the student is again reminded that shading must be secondary to outline, and that therefore

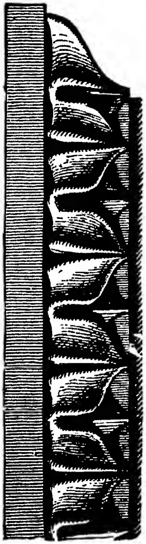


Fig. 217.

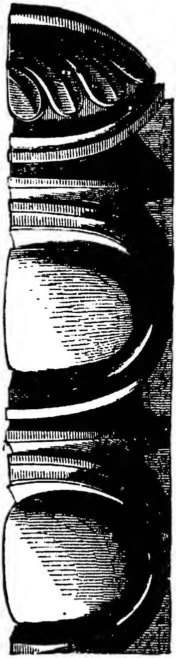


Fig. 218.

it is intended that each of the studies here given is to be drawn *twice*, first, as distinct practice in *outline;* and, secondly, another outline having been drawn, the shading may be added, but on no account is the shading to be

begun until the outline can be drawn with facility. In commencing to draw this moulding, which is used as a decoration for the cyma reversa, set off the widths of the leaves, and draw perpendiculars, which will afterwards be the middle lines for the darts or tongues. Exactly in the middle of each of these spaces draw other perpendiculars for the midribs of the leaves. The curves are next to be drawn, being careful to balance the sides accurately.

Fig. 218 is the Greek ornament known as the egg and tongue. It is used as a decoration for the ovolo moulding. The method of commencing to draw this is the same as in the last example, and thus any further instructions are unnecessary.

Figs. 219 and 220 are studies of the wave-line. They are, in fact, the cyma recta repeated, the depth being lessened in Fig. 220.

Fig. 221 is a study of the elementary lines of a running scroll, formed of the wave-line, with the addition of spirals. Care must be taken in drawing these spirals, so that they may proceed from the stem in a smooth and continuous manner. They should start as a continuation of the wave-line so gradually, that if the stem beyond the spiral were removed, the scroll would be perfect, and that if the scroll were taken away the wave-line would remain uninjured. This should also be the case in Fig. 222, in which tendrils are added to the scrolls

Fig. 223 is a further elaboration of the same design, the lines being doubled.

Fig. 224 is another simple running pattern based on the wave-line.

Figs. 225 and 226 are ancient borders worked on the ogee or cyma reversa moulding. These are both to be started in the same manner as Figs. 217 and 218—namely, by dividing the width into equal parts for the middle line of the arch or of the tongue, and dividing each space again to obtain the middle line of the dart or flower. The main forms are then to be sketched in.

Fig. 227 is the **Guilloche,** or chain, and is formed by concentric circles overlapping each other. This pattern is easily drawn with compasses, but is here given as a free-hand study, in order to give the student an exercise in severity and accuracy of form.

LINEAR DRAWING BY MEANS OF INSTRUMENTS *(continued)*.

Figs. 228 and 229, combined into one view, are two designs for wooden gates, and are so simple that they will scarcely require any instructions as to copying.

The posts *m* and *n* are, of course, to be drawn first; then the base, *k*, and moulding, *l*; next the framing, *a*, *b*, *c*, *d*, of each gate.

In Fig. 228 the rail, *e*, is to be drawn next, and in the upper compartments the quatrefoils, *g*, and in the lower, the bars, *h*, and curved stay are to be drawn.

In the rectangle formed by the framing in Fig. 229 draw diagonals, and at their intersection the circular opening. Now draw the cross-framing, *o p*, and the vertical bars. The details will now be added without much difficulty

Fig. 230 is the plan of a folding (or French) window and shutter-box. *a* is the framing of the window; *b*, the window; *c d*, the folding shutter closed; *c d*, ditto folded: *e f i* the casing of the shutter-box; *g*, the wall; *h*, the inner casing.

DOORS.

The most common kinds of doors are constructed of several simple boards, not fixed with glue or any tenacious substance, but by nailing transverse pieces upon the back of the boards laid edge to edge. The transverse pieces thus nailed are called *ledges* or bars, whence the door is said to be ledged or barred. In this case one of the edges at every joint is beaded on both sides, or at least on the face which is outside, the edges being placed on the inside.

Doors of this description are generally employed in cottages or out-houses.

Where doors are required to combine strength, beauty, and durability, a frame, joined by mortise and tenon, must be constructed with one or more intermediate openings, each of which must be surrounded by three or more parts of the frame, which have grooves ploughed in the edges for the reception of boards to close the openings, inserted as in the last figure.

The parts of the framing which are horizontal when the door is hung or fixed upon its hinges, are called *rails*—upper, middle, and lower. The extreme parts of the frame

to which the rails are fixed are called the *stiles*, and the intermediate ones are termed *mountings*. The boards by which the interstices are closed are called *panels*.

Fig. 231 is the elevation of a pair of folding-doors, with mouldings and cornice. In this example it is desirable to commence by drawing the entire framing and cornice, with their mouldings. Then draw a central perpendicular, on which mark off the heights of the various rails and panels, and draw horizontal lines for the upper and lower edges of these. From the central perpendicular next set off the width of the stiles, &c., and draw the necessary perpendiculars. The mouldings to the panels may now be added.

Fig. 232 is the section on a larger scale of the frieze and cornice, showing how the various members are put together. The ornamental moulding, *f*, is in this design supposed to be made of pressed zinc, in which some very beautiful patterns are now worked, which are by far more durable than those made of composition.

Fig. 233 shows the manner in which such doors meet in the middle.

GOTHIC TRACERY.

Although, as has already been stated, the whole subject of Gothic architecture, in both stone and wood, will be treated of in a special manual, still a few examples of tracery are given here, knowing that the joiner is often called upon to put together such on panels in churches or mansions, and that a knowledge of the basis of the construction will be of service to him. The limits of this manual, however, utterly preclude a systematic treatise on the characteristics of the several periods of mediæval art. These examples will, however, in some degree prepare the pupil for the subsequent and more extended study.

Fig. 234 is the elementary study upon which the subsequent figure is based.

Having drawn the circle, describe on the diameter two opposite semicircles, meeting at the centre, *a*.

Divide one of these into six equal parts, and set off one of these sixths from *i* to *n*.

Draw *a n*, and divide it into four equal parts. From the middle point of *a n* draw a line passing through the centre of the semicircle, and cutting it in *c*. From *c* set off on this line the length of one of the fourths of *a n*.

This point and the two in *a n* will be the centres for the interior curves.

Fig. 235 is the further working out of this elementary figure. It is desirable that a larger circle should be drawn. Then, when the figure has been carried up to the stage shown in the last, all the rest of the curves will be drawn from the same centres.

Fig. 236 is the elementary form of the tracery shown in Fig. 238, and is based on the problem, "To inscribe three equal circles in a circle" (Fig. 72, "Linear Drawing"), which, in order to save the student the trouble of reference, in the event of his not being quite certain as to the construction, is here repeated in Fig. 239.

At any point, as A, draw a tangent, and A G at right angles to it.

From A, with radius O A, cut the circle in B and C.

From B and C draw lines through O, cutting the circle in D and E, and the tangent in the point F (and in another not given here, not being required).

Bisect the angle E at F, and produce the bisecting line until it cuts A G in H. From O, with radius O H, cut the lines D C and E B in I and J. From H, I, and J, with radius H A, draw the three required circles, each of which should touch the other two and the outer circle.

Returning now to Fig. 236, having inscribed three equal circles in a circle, join their centres, thus forming an equilateral triangle. From the centre of the surrounding circle draw radii passing through the angles of the triangle and cutting the circle in points, as *d* and two others. Draw *e d* and bisect it by *c g;* then the centres for the curves which are in the semicircle will be on the three lines *d c*, *c g*, and *c e*.

These curves are called "*foliations*," or "*featherings*," and the points at which they meet are called "*cusps*."

The completion of this study is given in Fig. 238.

Fig. 237 shows the elementary construction of Fig. 240.

Draw two diameters at right angles to each other, and join their extremities, thus inscribing a square in the circle.

Bisect the quadrants by two diameters cutting the sides of the square in points, as *g*. Join these points, and a second square will be inscribed within the first.

The middle points of the sides of this inner square, as *b*, *c*, *d*, are the centres of the arcs which start from the extremities of the diameters.

From *b*, with radius *b d*, describe an arc, and from *g*, with radius *g c*, describe another cutting the former one in *e*. Then *e* is the centre for the arc *i g*, which will meet the arc struck from *b*, in *i*. Of course, this process is to be carried on in each of the four lobes.

Fig. 240 is the completed figure. The method of drawing the foliation will have been suggested by Fig. 235, and is further shown in the present illustration.

Fig. 241*a* shows the skeleton lines of Fig. 241*b*. Divide the diameter into four equal parts, and on the middle two, as a common base, construct the two equilateral triangles *o i n* and *o i m*.

Draw lines through the middle points of the sides of the triangles, which, intersecting, will complete a six-pointed star in the circle, the angles of which will be the centres for the main lines of the tracery.

Fig. 241 is the completed figure.

The small figures, 242 and 243, will be understood without further instruction than is afforded by the examples.

Fig. 244 shows the construction of the tracery in a square panel.

From each of the angles of the square (the inner one in this figure), with a radius equal to the length of the side of the square, describe arcs; these intersecting will give a four-sided curvilinear figure in the centre. Draw diagonals in the square.

From the point where the diagonal intersects the curve *b* (the middle line of the three here shown) set off on the diagonal the length *c b*, viz., *b m*.

From *q*, with radius *m q*, describe an arc cutting the original arc in *o*.

Make *m r* equal to *m o*.

From *o* and *r*, with radius *o r*, describe arcs intersecting each other in *i*: produce these until they meet the curve *p* in *n*.

The foliation and completion as per Fig. 245 will now be found simple.

Fig. 246 is a quatrefoil, and Fig. 247 a cinquefoil, the construction of which has been fully described in "Linear Drawing," Figs. 35 and 57.

Fig. 248 is given as a closing illustration of panel tracery; and it is hoped that, with the instructions already given and the elementary figures 249 and 250, the student will be able to draw this example without further aid.